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DEPARTMENT OF COMMERCE

UNITED STATES BUREAU OF MINES
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MINING METHODS AND COSTS AT METAL MINES OF THE UNITED STATES

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CHARLES WILL WRIGHT

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DEPARTMENT OF COMMERCE - BUREAU OF MINES

MINING METHODS AND COSTS AT METAL MINES OF THE UNITED STATES[1]

By Charles Will Wright[2]

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1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6503."

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INTRODUCTION

The purpose of this paper is to present briefly certain preliminary results of the study of mining methods by the United States Bureau of Mines; to show the relative importance of each method in terms of tonnages mined and man-hours consumed; to give to the mining engineers and particularly to the young student of mining a better understanding of the principal mining methods; and to indicate changes now in progress and to present suggestions for improvements in the art of mining.

Questions of mine development and details of underground practice such as drilling and blasting, loading, hauling, hoisting, ventilating, pay systems and mine management are omitted, as these have been or will be discussed in other bureau publications.

Statistics show that only about 400 metal mines in the United States produced $100,000 or more in 1929. These mines represented about 90 per cent of the total metal production. The study is therefore not an appalling one, as some may think, but a relatively limited one.

ACKNOWLEDGMENTS

The writer is indebted to C. F. Jackson and J. B. Knaebel for their assistance and to the economics and health and safety branches of the United States Bureau of Mines for their help in securing the statistical data. A special expression of thanks is due to the mine officials who gave so generously of their time to prepare detailed reports on their mining operations, which reports, published by the bureau as Information Circulars, are the basis of this study. A list of these Information Circulars and their authors is added at the end of this paper, each paper having a reference number, as (1), etc., used throughout the text and in most of the tables.

ORE OCCURRENCE

The engineer is interested not only in the size, shape, dip, and metal content of an ore deposit to be mined, but also in the distribution of the metal-bearing minerals in the deposit. These minerals sometimes occur in rich shoots or concentrated in small masses or areas, and in such cases selective mining and hand sorting usually give the best results. There are instances of failures resulting from attempts to mine and mill an entire orebody, where smaller-scale operations, requiring less plant and equipment and using selective mining and hand sorting, might have succeeded.

The nature of the mineral, whether a sulphide or oxidized ore or a combination of the two, has an important bearing on its ultimate value. The fineness and associations of the mineral particles in the ore must also be determined, and neglect of this may result in a failure. Certain copper-zinc and lead-zinc ores are so finely intermixed that their separation, even by the finest grinding, is only partial, and only at a high cost is it possible to make a commercial product from them.

Next to the characteristics of the deposit, the conditions of the inclosing rocks should be investigated. The strength of the roof or walls as well as that of the orebody itself must be considered in determining the ultimate value of an ore and the mining method

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that should be used. Some ore deposits have no sharply defined walls as the ore minerals are disseminated in the country rock, and the limits of minable ore are determined by the amounts of ore minerals present. These limits vary with metal prices and improvements in the technique of mining and milling. It is from such deposits that to-day some of our largest production is coming.

CLASSIFICATION OF MINING METHODS

Classifications of stoping methods have been published from time to time in the technical press and in the bulletins of various professional associations. These classifications have been based upon the method of support, direction of working, sequence of operations, methods of handling broken ore, and combinations of these methods. Charts have been prepared, including all variations and combinations of methods, showing that upwards of one hundred and fifty such variations and combinations are in use. These variations have resulted in confusing somewhat the fundamental distinctions between the principal methods.

Certain methods extensively employed in the Southwest, and there considered to be distinct, may be thought by the engineer in the Lake Superior region to be of secondary importance and not to be included in a simplified classification. It would seem, therefore, that the simpler and more condensed the classification, the more readily and generally it will be accepted.

In the last analysis, the method to be applied is governed primarily by those characteristics of the deposit which determine the area of back and size of excavation which will be self-supporting during the period of stoping, and by the nature, size, and spacing of supports required to maintain these openings, and by the requirements as to permanently supporting the surface against subsidence. This is true whether the deposit be large or small, flat, inclined or vertical, and whatever may be the grade of ore and distribution of minerals. These last factors are recognized as having an important bearing upon the details and variations of the principal method selected, but primarily the method to be employed hinges upon the question of support. It is therefore logical to base a classification of mining methods upon the method of support, as follows:

Stopes naturally supported:

1. Open-stope method, including open stopes with casual pillars or with regular arrangement as in the room-and-pillar method and the sublevel-stoping method.

Stopes artificially supported:

2. Shrinkage method, with or without pillars.
3. Cut-and-fill method, with or without temporary supports.
4. Square-set or stull-set method.

Caved stopes:

5. Caved-stope methods, including top slicing, sublevel caving and block caving.

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Combined underground methods:

6. Combinations of supported and caved-stoping methods.

Surface mining:

7. Opencut methods.

The above classification does not take into consideration the direction of stoping as "underhand" or "overhand," "horizontal or rill," the sequence of working as "advancing" or "retreating," or the methods of handling as by "chutes," "branch raises," "scrapers," or "hand shoveling," although these are recognized as important variations of the principal methods.

In this classification "stopes naturally supported" includes all stopes where the excavated ore is not replaced by other support during the period covered by mining operations in the stope. Props and stulls may be used in such stopes, however.

"Stopes artificially supported" includes all those stopes in which the excavated ore usually is replaced by filling (ore or waste) or by square-set or stull-set timbering. Where supported by broken ore during stoping operations, the stopes are not always filled after the ore has been removed.

The entire classification includes six principal methods, and to these has been added a seventh, namely "combined underground methods," to include stoping operations where two methods are systematically employed together in a regular scheme for mining each block of ore, the principal method being dependent for its success upon the application of the other or subordinate method.

Again, at some mines a portion of the ore deposit is mined by the square-set method and another by cut-and-fill, or the upper portion by open-pit methods and the lower portion by shrinkage; at some mines different methods are used for different portions of the same orebody, and in classifying these mines the method is chosen by which the greatest tonnage is produced. Two independent methods used on different portions of the same deposit are not considered combined methods.

In the above classification all variations of methods not widely and generally understood are deliberately omitted, and it is believed that all known methods of stoping will fall logically under one of the seven captions of this classification.

RELATIVE IMPORTANCE OF EACH MINING METHOD AS APPLIED TO METAL MINES IN THE UNITED STATES

Two tables have been prepared; the first shows the tonnages of each metal-bearing ore mined by each method, and the percentages of the total tonnage; the second shows the man-hours worked in the mines according to the metal produced, accident data according to the mining method used, and the percentage of labor employed for each method. A comparison of these two tables brings out the following points of interest.

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Table 1 shows that in 1929 the total output of these $100,000 mines was 169,969,366 tons from 405 mines. Forty-two per cent of this total was mined from opencuts, 21 per cent was produced by the open-stope method, and the caved-stope methods were responsible for 25 per cent.

Table 2 shows that the total man-hours worked, 162,645,375, is about the same as the total tonnage mined, indicating that approximately 1 ton was mined for each man-hour worked. The square-set method consumed 25 per cent of the total labor, to produce 4.6 per cent of the total tonnage, while the open-stope method produced 21 per cent of the tonnage with the same labor consumption as in the square-set method. The opencut method was responsible for 42 per cent of the tonnage, with a consumption of only 14 per cent of the total labor. Fifteen times more tonnage was mined per man-hour by the open-pit method than by the square-set method.

The accident records show that the opencut, sublevel-caving and top-slicing, and open-stope methods had the lowest accident rates or best records, and the square-set, cut-and-fill, block-caving and shrinkage methods had the highest accident rates or worst records.

Table 1.- Tonnages classified according to mining method at metal mines with individual production of more than $100,000 in 1929

Mining method	No. mines	Gold ore, tons	No. mines	Copper ore, tons	No. mines	Silver, lead, and zinc ore, tons	No. mines	Iron ore, tons	No. mines	Total tons, ore	Per cent
Square-set	7	379,022	26	4,318,294	28	3,121,746	-	-	61	7,819,062	4.6
Cut-and-fill	2	13,150	6	1,573,135	11	664,252	2	305,575	21	2,556,112	1.5
Shrinkage	11	5,645,110	12	2,306,930	10	2,011,500	4	1,070,608	37	11,034,148	6.5
Open-stope	11	364,516	12	6,121,545	113	15,502,250	34	13,298,362	170	35,186,673	20.8
Top slicing	-		-	-	-	-	37	15,904,288	37	15,904,288	9.4
Sublevel caving	-	-	-	-	-		17	7,303,976	17	7,303,976	4.3
Block caving	-	-	7	18,576,196	-	-	-	-	7	18,576,196	10.9
Open-pit	-	-	7	31,605,847	-	-	48	39,883,064	55	71,488,911	42.0
Total	31	6,401,798	70	64,501,947	162	21,299,748	142	77,765,873	405	169,969,366	100.0

1 Reduced to short-ton basis.

Table 2.- Man-hours worked and accident data classified according to mining method at metal mines with individual production of more than $100,000 in 1929

Mining method	Man-hours worked					Per cent	Accidents per thousand 300-day workers	
	Gold	Copper	Silver, lead, and zinc	Iron	Total		No. killed	No. injured
Square-set	2,028,328	21,312,106	17,004,829	-	40,345,263	24.8	3.91	390
Cut-and-fill	207,600	6,628,064	3,642,496	612,712	11,090,872	6.8	4.09	223
Shrinkage	3,916,770	5,584,400	4,175,792	997,000	14,673,976	9.0	5.37	302
Open-stope	2,018,640	8,370,798	18,011,090	15,232,038	39,965,832	24.6	3.26	258
Top slicing	-	-	-	14,826,200	14,826,200	9.1	3.15	74
Sublevel caving	-	-	-	6,922,448	6,922,448	4.3	2.39	57
Block caving	-	11,679,624	-	-	11,679,624	7.2	4.81	219
Open-pit	-	9,097,408	-	14,045,752	23,143,160	14.2	2.18	112
Total	8,171,338	62,672,400	42,834,207	52,636,150	162,647,375	100.0	3.50	238

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AVERAGE RESULTS OF EACH MINING METHOD, CLASSIFIED ACCORDING TO METALLIC MINERAL MINED

A series of tables has been prepared to show the tonnages and metal content of ores mined by each method, the man-hours worked, and the tonnage of ore and units of metal produced per man-hour at the gold, copper, lead-zinc, and iron mines. In reviewing these tables, one will note the amounts of ore of each metal mined by each method; and, having the average output per man-hour, one can easily estimate the total amount of labor employed at the mines if the ore or metal production is known, or vice versa.

GOLD MINES — 1929

All mines in the United States with individual output valued at over $100,000

Mining method	No. of mines	Man-hours	Tons mined	Per cent of total tonnage	Yield, ounces per ton	Man-hours	
						Per ton	Per ounce output
Square-set	7	2,028,328	379,022	5.9	0.35	5.35	15.3
Cut-and-fill	2	207,600	13,150	.2	1.03	15.78	15.3
Open-stope	11	2,018,640	364,516	5.7	.42	5.54	13.2
Shrinkage	11	3,916,770	5,645,110	88.2	.17	.69	4.01
Total	31	8,171,338	6,401,798	100.0	0.20	1.27	6.41

COPPER MINES — 1929

All mines in the United States with individual output valued at over $100,000

Mining method	No. of mines	Man-hours	Tons mined	Per cent	Yield, pounds per ton	Man-hours	
						Per ton mined	Per pound output
Square-set	26	21,312,106	4,318,294	6.7	93.0	4.95	0.054
Cut-and-fill	6	6,628,064	1,573,135	2.4	67.5	4.18	.062
Shrinkage	12	5,584,400	2,306,930	3.6	33.6	2.45	.073
Open-stope	12	8,370,798	6,121,545	9.5	26.7	1.37	.051
Block caving	7	11,679,624	18,576,196	28.8	18.6	.63	.034
Opencut	7	9,097,408	31,605,847	49.0	20.6	.29	.014
Total	70	62,672,400	64,501,947	100.0	27.4	0.95	0.034

LEAD-ZINC MINES — 1929

All mines in the United States with individual output valued at over $100,000

Mining method	No. of mines	Man-hours	Tons mined	Per cent	Yield, pounds per ton	Man-hours	
						Per ton mined	Per pound output
Square-set	28	17,004,829	3,121,746	14.7	246.6	5.45	0.022
Cut-and-fill	11	3,642,496	664,252	3.1	161.7	5.48	.034
Shrinkage	10	4,175,792	2,011,500	9.4	144.4	2.04	.015
Open-stope	113	18,011,090	15,502,250	72.8	68.2	1.12	.017
Total	161	42,834,207	21,299,748	100.0	91.3	2.01	0.022

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IRON MINES — 1929

All mines in the United States with individual output valued at over $100,000

Mining method	No. of mines	Man-hours underground	Tons mined[1]	Per cent	Production, of iron tons	Yield per ton mined, tons	Man-hours Per ton mined	Man-hours Per ton iron
Cut-and-fill	2	612,712	272,835	0.4	149,369	0.550	2.25	4.09
Shrinkage	4	997,000	955,900	1.4	435,145	.456	1.04	2.28
Open-stope	34	15,232,038	11,873,538	17.1	4,933,589	.415	1.28	3.08
Top slicing	37	14,826,200	14,200,257	20.5	7,399,874	.520	1.05	2.02
Sublevel caving	17	6,922,448	6,521,407	9.4	3,444,545	.529	1.06	2.00
Opencut	48	14,045,752	35,609,878	51.2	16,877,752	.475	.39	.82
Total	142	52,636,150	69,433,815	100.0	33,240,274	.478	0.76	1.60

1 Mines represented = 33,140,274 long tons iron
Total output, 1929 = 37,601,850 long tons iron.

CONSUMPTION OF LABOR, POWER, AND EXPLOSIVES, AND AVERAGE COSTS PER TON MINED BY EACH METHOD

A review of the following table brings out rather strikingly the advantages or disadvantages of the different methods of mining with reference to consumption of labor, power, and explosives, as well as to mining costs. These consumption figures and costs show wide variations, in some instances as much as a thousand per cent.

The table shows the average of the mines from which we have specific data, and the number of mines represented is indicated in each case. Of special interest is the comparison of man-hours per ton with mining costs. One might almost make the formula:

Cost of mining = man-hours per ton x $1.

As costs vary with the prices paid for labor and supplies and with locality, the dollars and cents figures are not as important for comparative purposes as the expenditure in units of labor, power, explosives and other supplies per ton mined or per unit of metal produced.

One might ask, "Why give costs in dollars, especially average costs?" No mine can be considered an average mine. Costs often vary widely at the same mine from year to year due to greater or less development work, change in rate of production, depth of workings, amount of water to be handled, etc. Again, a direct comparison of costs of two mines using the same method is misleading, as no two mines have the same size and shape of orebody, grade of ore, strength of wall rocks, or other operating conditions. However, the average costs do indicate in a general way the difference in cost of mining by the different methods; these are given below for a limited number of mines.

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Average results for different mining methods

Mining method	Man-hours per ton, all underground labor	Tons per man-shift, all underground labor	Explosive used per ton, pounds	Power, kw.h. per ton	Total underground cost per ton
Square-set	5.15	1.553	1.363	34.9	$4.825
Average of	61 mines	61 mines	10 mines	19 mines	11 mines
Cut-and-fill	4.34	1.843	.660	10.045	$3.076
Average of	21 mines	21 mines	5 mines	4 mines	5 mines
Shrinkage	1.33	6.015	1.656	15.33	$2.682
Average of	37 mines	37 mines	18 mines	16 mines	16 mines
Open-stope	1.17	6.837	.844	8.90	$1.250
Average of	170 mines	170 mines	22 mines	17 mines	19 mines
Sublevel caving	.95	8.421	.605	13.00	$1.438
Average of	17 mines	17 mines	4 mines	2 mines	2 mines
Top slicing	.932	8.584	.520	7.252	$1.208
Average of	37 mines	37 mines	13 mines	12 mines	3 mines
Caving	.628	12.739	.244	3.0	.516
Average of	7 mines	7 mines	3 mines	3 mines	4 mines
		Surface			
Opencut	.324	24.691	.308	2.71	.309
Average of	55 mines	55 mines	3 mines	3 mines	3 mines

The following table shows in a rough way the relative consumption of explosives and power according to metal mined; the number of mines from which the data were obtained is indicated in each case. With data from more mines, these averages would be more representative.

Explosives and power consumption according to metal mined

Metal	Tons of ore represented	Explosives, pounds per ton	Power, kw.h. per ton
Iron:			
30 underground mines	14,298,700	0.548	8.38
Lead and zinc:			
15 underground mines	3,159,701	.920	17.65
Copper:			
10 underground mines	11,293,237	.439	7.64
3 open-pit mines	21,246,804	.308	2.71
Gold:			
8 underground mines	5,554,410	.844	9.72

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FACTORS TO BE CONSIDERED WHEN SELECTING A MINING METHOD FOR A GIVEN ORE DEPOSIT

In considering the possible commercial exploitation of any ore deposit, its probable tonnage, grade, and production-costs must be taken into account. The mining method employed in the extraction of the ore will determine largely the production-costs. The method must naturally be the safest, most efficient and therefore the most economical, since an improper selection may result in high costs, low extraction, and loss of life.

The financial position of the mining company may be a factor in determining not only the amount of preliminary development work, but also the mining method to be used. Adequate development, particularly in depth and extent to the limits of the ore deposit or property line, although an initial drain on capital, usually results in greater flexibility and safety in mining, as well as in economy and longer life.

The stoping method best adapted to the extraction of an orebody depends upon a number of factors, such as the physical characteristics of the orebody and of the inclosing rocks, and the grade of ore and distribution of valuable minerals therein. These physical factors, as previously referred to, are the size, shape, dip, and strength of the orebody and the strength of the roof or walls of inclosing rock. The distribution of the ore minerals in the orebody will determine whether wholesale or selective mining should be applied. Low-grade deposits, where large-scale methods of extraction may be used, are often more profitable to mine than small high-grade deposits, where more costly methods are necessary.

The availability and cost of timber and material for use as waste-fill may have an important bearing on the choice of a stoping method! also the chemical nature of the ore has in some instances modified the choice of a mining method; the tendency of massive sulphides to oxidize if broken and left for any considerable time in the stope may result in low recovery by flotation or cause disastrous mine fires.

DESCRIPTION OF EACH MINING METHOD, GIVING ADVANTAGES, DISADVANTAGES, AND CONDITIONS SUITABLE FOR APPLICATION

Open-Stope Method

The open-stope method is one of the most ancient, and was used over 2,000 years ago at certain mines on the Islands of Sardinia and Cyprus, where the Romans mined lead-silver and copper ores, and 1,000 years ago in the Province of Trento in northern Italy. The Mons Argentarius group of silver-lead mines neat Trento, with its many square miles of stoped areas, may still be visited, and one marvels at the great extent of these underground rooms and pillars, excavated by the ancients with chisel and pick.

An open stope is an underground chamber from which the ore has been extracted and in which the roof or walls are supported by pillars of ore or waste at intervals depending upon the strength of the roof or walls, or by props, stulls, or cribbs. This method is used in mining all types of ore deposits, from flat beds to vertical veins.

Underhand stoping or the mill-hole open-stope method, may be used where the roof or walls of the orebody are strong and the ore itself stands well. It is the open-pit bench-m8ning method carried underground. This method is used at the Mascot mine of the

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American Zinc Co. in Tennessee and the iron mine (1) of Witherbee Sherman & Co. at Mineville, N. Y. (figs. 1 and 2).

The more general application of the open-stope method embodies attack by overhand stoping, as at the copper mines (20) in Michigan (fig. 3) or by the breast method as in the lead and zinc mines (2, 3, 6, 10, 15) of Tri-State district (fig. 4). Still another variation in open-stope mining is the use of sublevels spaced from 30 to 50 feet apart (11, 12, 17), one above another, and mining the ore into an open chamber at the ends of these sublevels, as indicated in the accompanying sketch. This method is well developed at the Burra Burra mine (5) near Ducktown, Tenn. (fig. 5).

Application.- Open-stope methods are applicable to mining strong or moderately strong orebodies inclosed in strong or moderately strong wall-rocks, some latitude being allowed in this respect depending upon size, shape, and dip of orebody, depth below surface, character of slips and joints in the rock, grade of ore, and the particular variation of the open-stope method employed.

Advantages.- Where the method can be applied, the following are the principal advantages:

1. Low stoping cost per ton, considering that the ore is usually hard.
2. Mechanical loading and haulage methods are easily applied.
3. Ability to follow irregularities in the ore body to secure high total extraction
4. Sorting of waste is possible to some extent and lean ore or barren rock within the ore body may be left in place as pillars.
5. Selective mining of different classes of material is often feasible (16).
6. The ore can be removed as fast as it is broken so that large capital sums are not tied up in broken ore.
7. The sublevel stoping variation of the open-stope method is safe and the accident rate is low (see Disadvantages).
8. Development is usually mostly in ore.

Disadvantages.- The disadvantage of the method are as follows:

1. In some variations of the method considerable ore must be left as pillars to support the roof or walls. Much of this, however, may be recovered later by robbing operations.
2. Except in the sublevel stoping variation, the accident rate is high. (See Table 2.)
3. It is often difficult to inspect and scale the backs and walls.
4. The ground is apt to cave eventually, removing the possibility of mining at some future time adjacent bodies of low-grade ore.

Results.- Two tables follow, one of which shows the results of the open-stope method for mining the different metals, in metal yield and man-hours consumed per ton mined at the mines that produced over $100,000 in 1929; the other gives the details of labor, explosives, and power consumption and costs per ton mined at the individual mines using this method.

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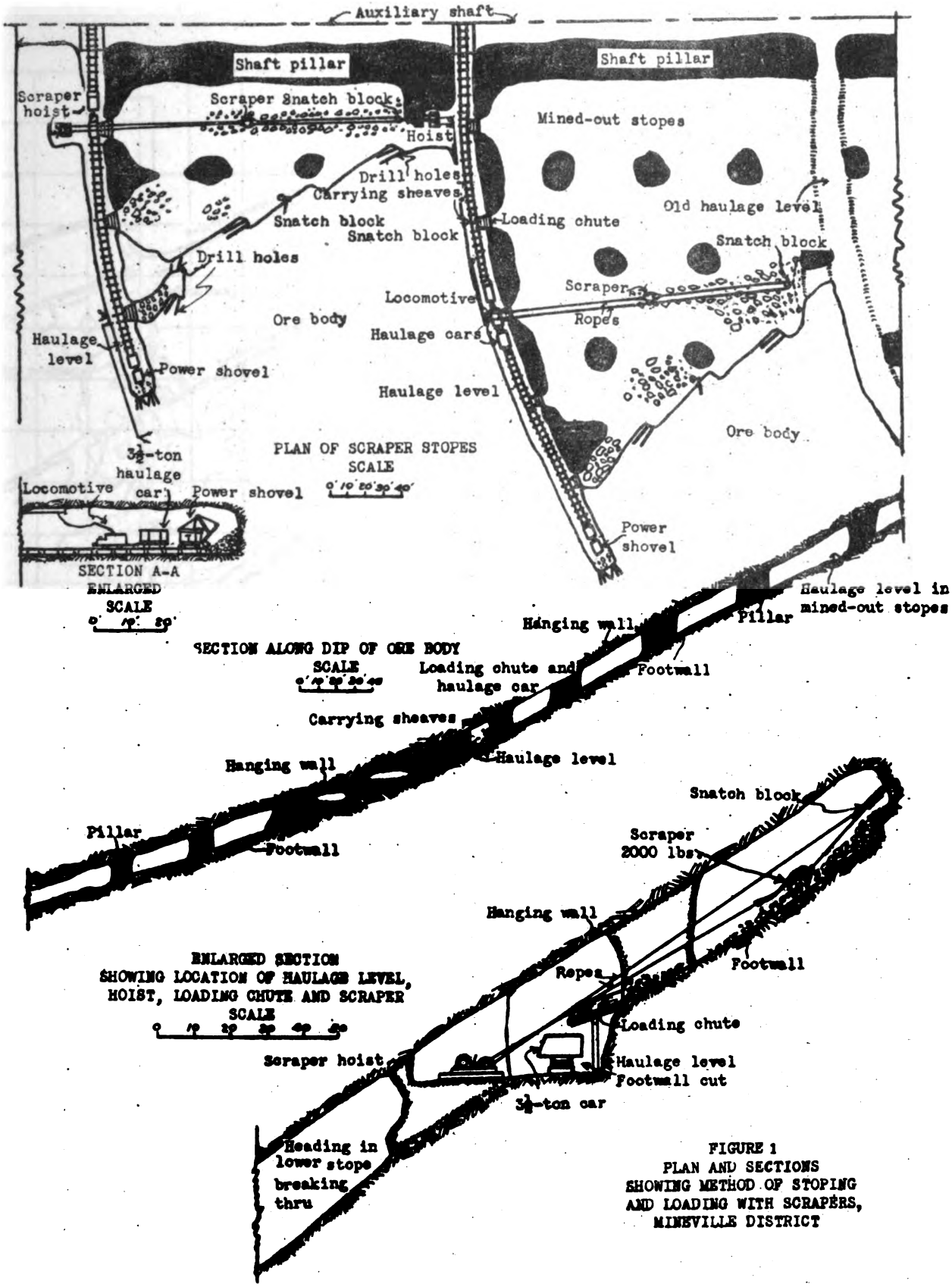

FIGURE 1
PLAN AND SECTIONS
SHOWING METHOD OF STOPING
AND LOADING WITH SCRAPERS,
MINEVILLE DISTRICT

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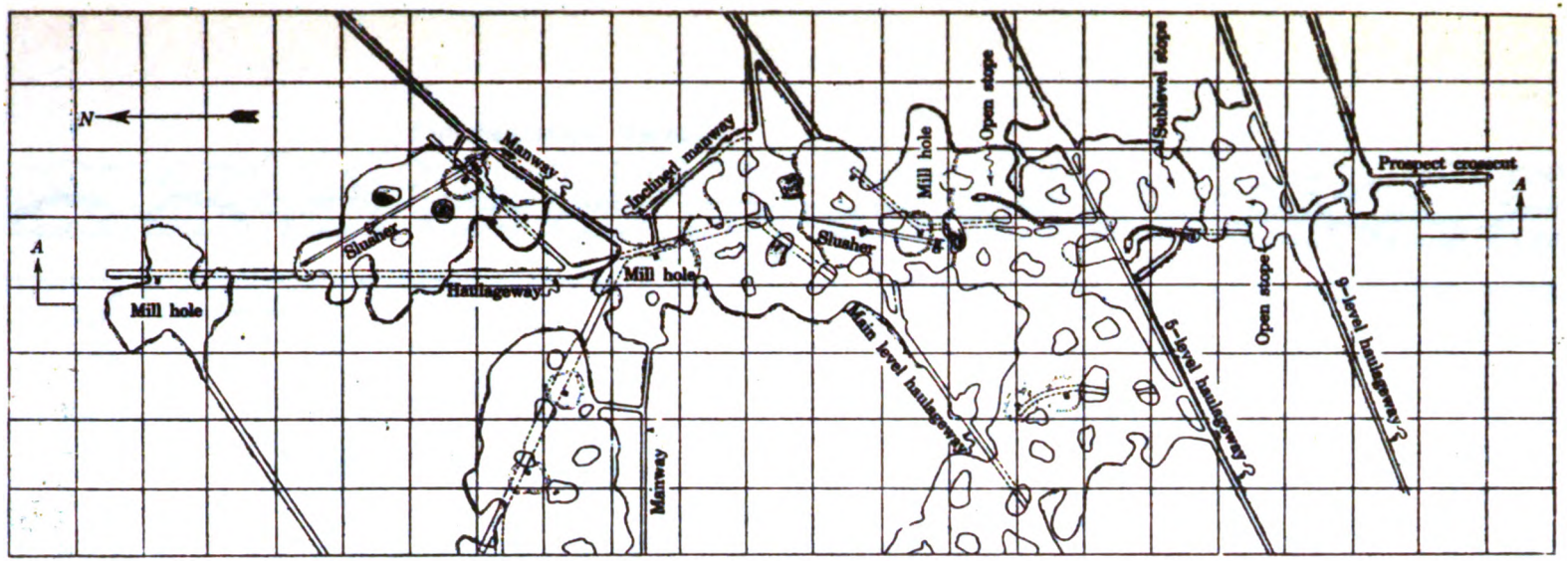
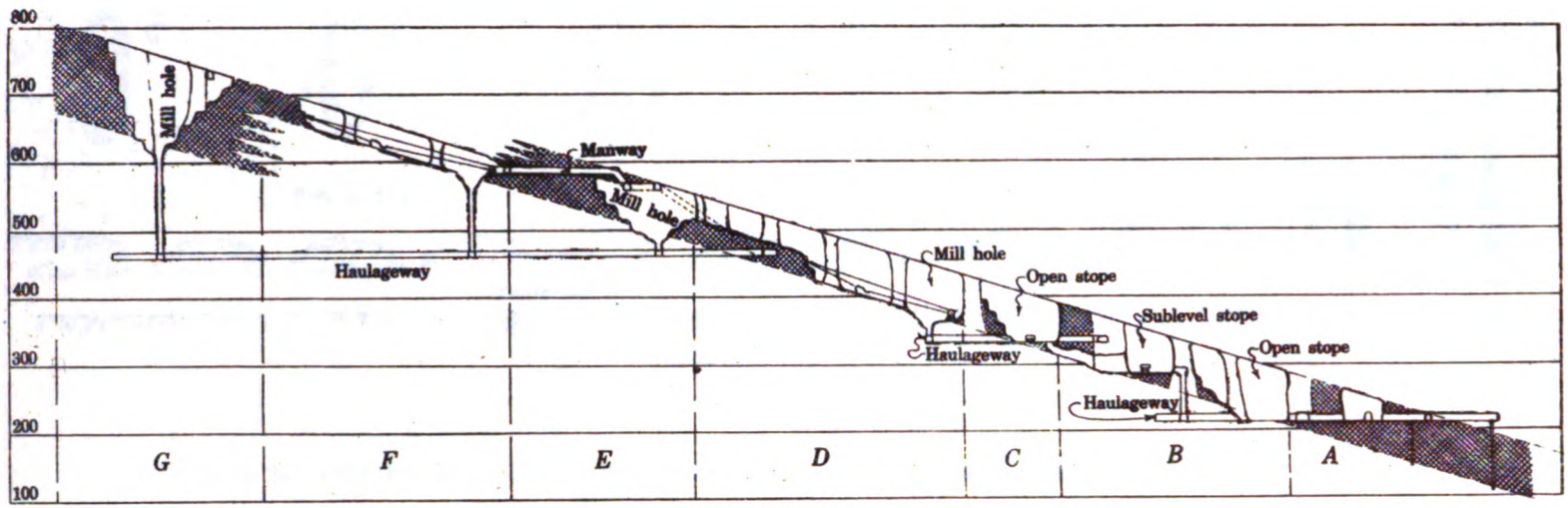


PLAN OF A PORTION OF NO. 2 MINE, MASCOT, TENN.



SECTION *A-A*

Figure 2.- Open stope mill-hole method, Mascot, Tenn.

0 100 200 300 400 500
Scale in feet

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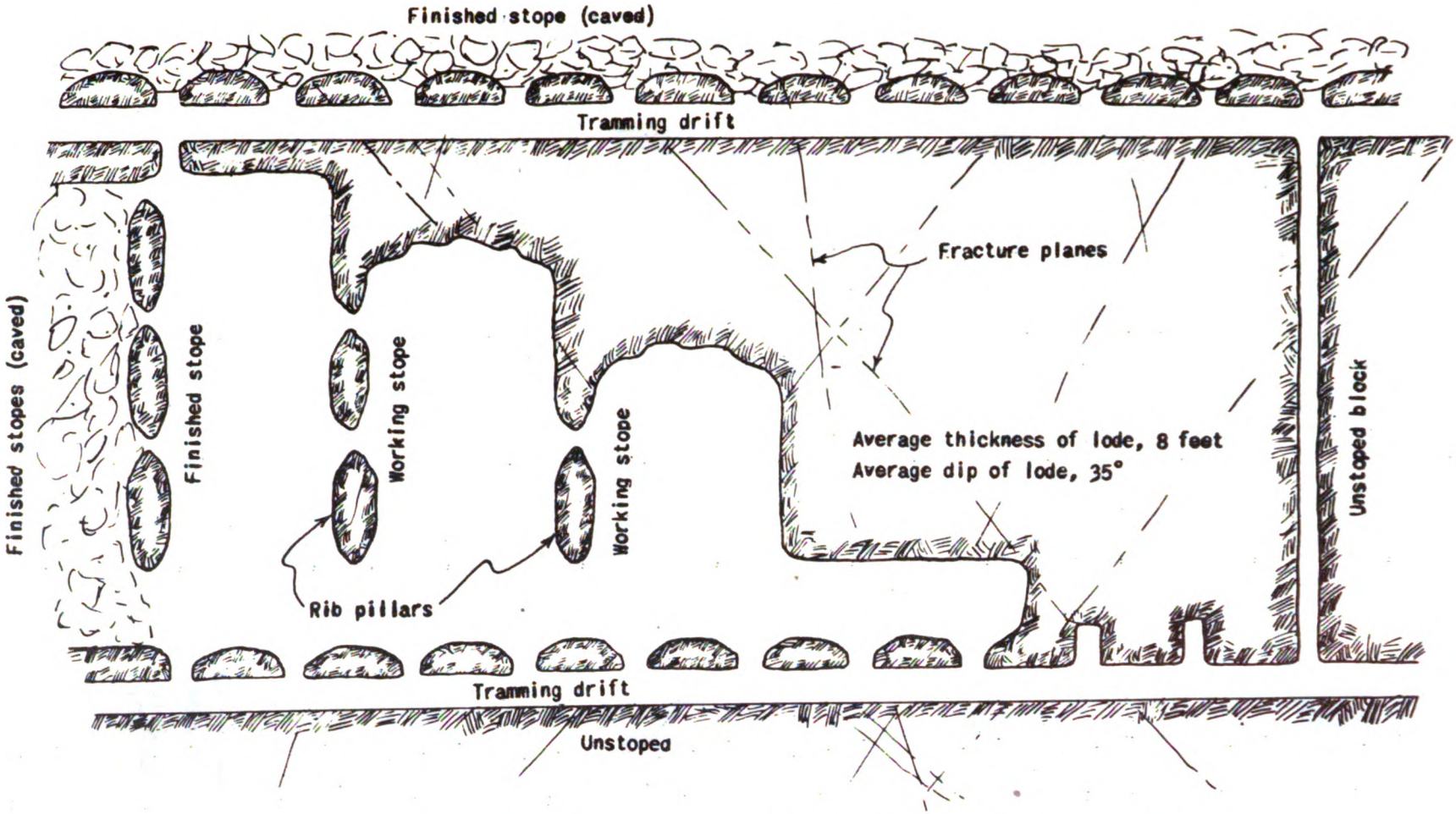

Figure 3.- Retreating system of open stoping with rib pillars.. Section in plane of lode

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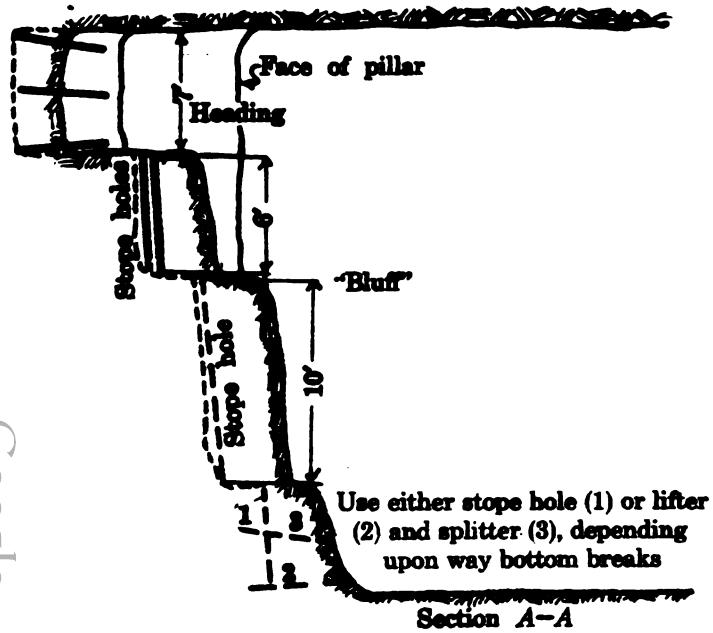

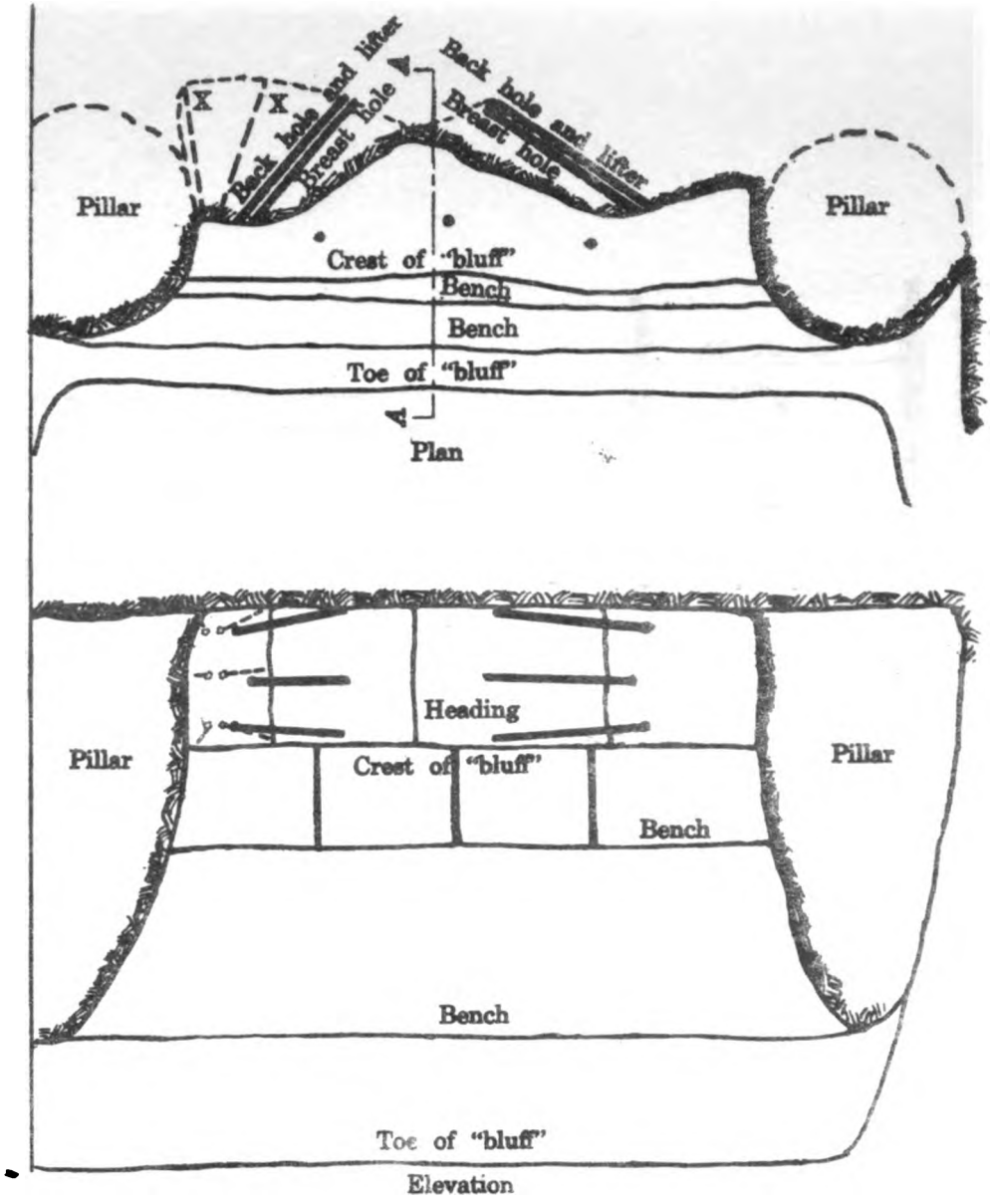

Figure 4.– Heading and stope or "bluff", Southeast Missouri District.

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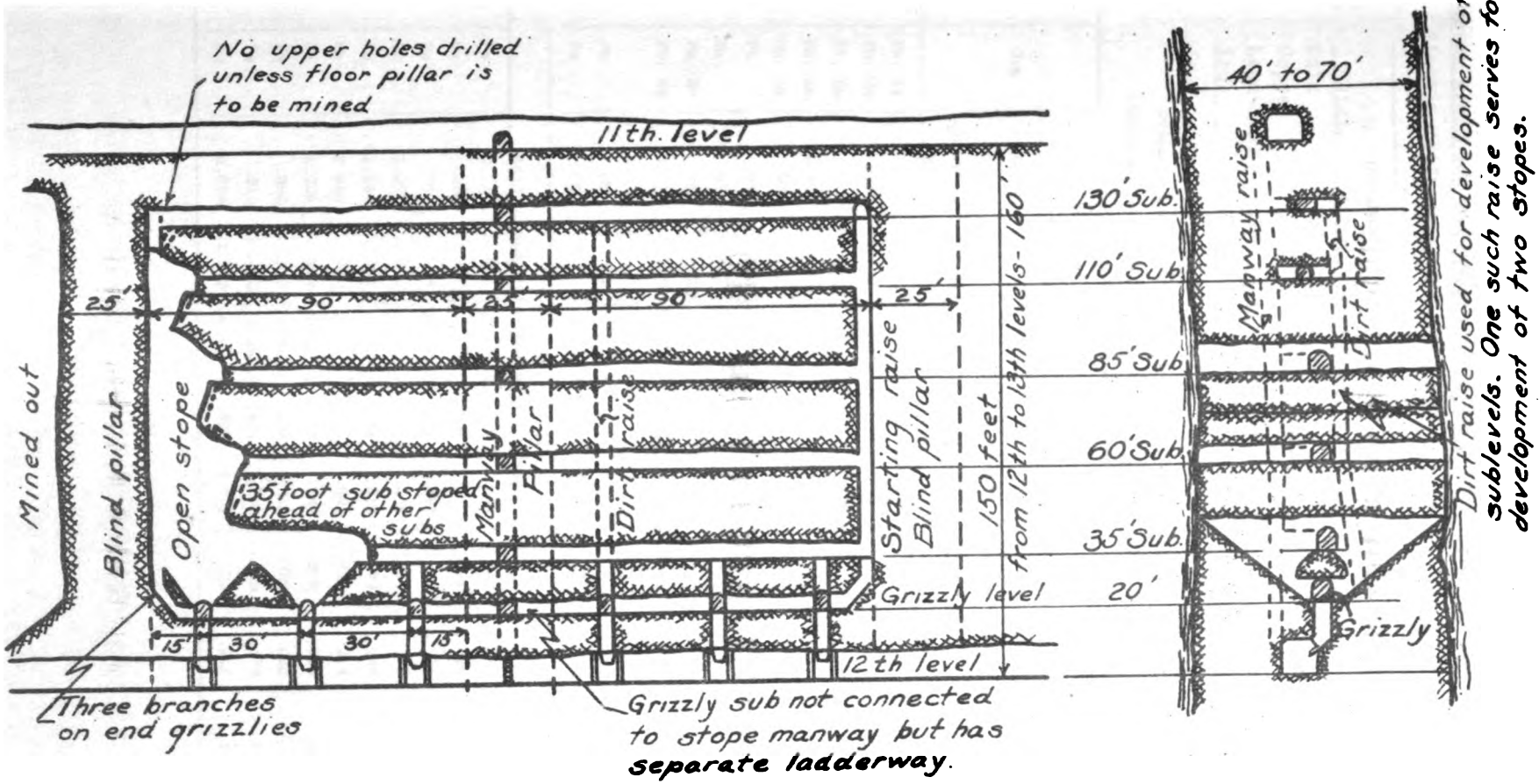

Figure 5. Sublevel stoping in moderately firm and hard ore; stope face overhanging.

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Metal yield and man-hours consumed per ton mined by open-stope methods at mines producing over $100,000 in 1929

Metal	Number of mines	Tons mined	Yield per ton	Man-hours per ton
Gold	11	364,516	0.42 oz.	5.54
Copper	11	6,121,545	26.7 lbs	1.37
Lead-zinc	113	15,502,250	68.2 lbs	1.12
Iron	34	11,873,538	.415 ton	1.28

Details of labor, explosives, and power consumption and costs per ton mined at mines using the open-stope method

FLAT BEDS; 10 TO 200 FEET THICK

Mine	Ore	Labor and supply consumption per ton: Labor, total underground, man-hr.	Explosives, pounds	Power, kw.h.	Direct mining costs per ton: Development	Stoping	Haulage and hoisting	General underground expense	Surface applicable to underground	Total	Refer I.C. list, p. 36
Tri-State No. 1	Pb, Zn	1.341	0.750	9.91	-	$0.630	$0.130	$0.09	$0.135	$0.985	(2)
Tri-State No. 2	Pb, Zn	.876	1.265	5.75	-	.708	-	.165	.120	.993	13)
Tri-State No. 3	Pb, Zn	.836	.875	4.17	-	.645	-	.162	.194	1.001	(10)
Waco	Pb, Zn	1.041	.594	6.65	-	.540)	.155	.057	.033	.785	(6)
Barr	Pb, Zn	.888	.805	6.09	-	.544)	.217	.069	.032	.862	(7)
S. E. Mo. No. 8	Pb	.875	.634	4.56	-	.483)	.222	.135	-	.840	(8)
Mascot	Zn	.831	.502	9.68	$0.053	.222	.278	.086	-	.639	(14)
Hartley-Grantham	Pb, Zn	.745	.741	1.89	-	.516	.196	.049	.021	.782	(15)
Presidio, Texas	Pb, Ag	5.770	2.000	23.70	1.065	2.276	.533	distributed	.127	4.001	(21)
S. E. Mo.	Pb	.827	.550	10.30	-	-	-	-	-	-	(9)
Hanover Bessemer	Fe	.782	-	-	(?)	.306	.167	(?)	(?)	(?)	(16)

BEDS DIPPING OVER 30°; 5 TO 150 FEET THICK

Marquette No. 1	Fe	1.172	0.901	11.56	0.218	0.770	0.244	0.180	-	1.412	(4)
Burra Burra	Cu	1.242	.755	7.92	.229	.332	.386	.145	0.043	1.135	(5)
Menominee No. 1	Fe	.701	.826	11.80	.211	.467	.173	.052	.027	.930	(12)
Michigan B	Cu	1.220	.991	-	.197	.498	.520	.008	-	1.223	(20)
Michigan C	Cu	1.104	.978	-	.379	.617	.479	.048	-	1.523	(20)
Mary	Cu	2.233	.782	-	.355	.545	.714	.214	-	1.828	(18)
Montreal	Fe	1.008	.850	12.61	.373	.349	.278	.106	.060	1.166	(17)
Mineville, N. Y.	Fe	.958	.937	10.91	.103	.416	.705	.026	-	1.250	(1)
Marquette No. 2	Fe	.919	.422	8.38	.224	.372	.129	.172	.059	.961	(11)
Spring Hill, Montana	Au	1.904	1.262	10.43	.377	1.072	.131	.218	.147	1.945	(19)

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Shrinkage Method

Shrinkage stoping was probably first employed for mining fairly thin, tabular ore bodies dipping at steep angles and composed of strong ore with firm walls, and is still the typical method of mining this class of deposit. It is also employed under quite different conditions.

The origin of the method is obscure, but it probably has been used for many years; it might easily have developed naturally in open-stope mining where the back became too high to reach from the bottom of the stope, thus suggesting the use of broken ore as a temporary working floor.

In this method (26 to 36) the ore is stoped upward from the level. The miners stand upon ore broken from preceding cuts, enough ore being drawn off after each cut to leave room to work between the top of the pile of broken ore and the unbroken back (fig. 6, 7, and 8). The pile of broken ore serves two principal purposes: that of a floor upon which to work in attacking the unbroken ore above; and that of a temporary support to the walls of the stope.

Application.- Shrinkage stoping is applicable to the mining of bodies of ore firm and strong enough to be self-supporting over considerable spans and with firm wall rocks. It finds its best application in the mining of narrow vein deposits dipping over 45°. Although it is often employed for mining wide ore bodies, it is probable that in many such cases other methods, such as sublevel stoping or modified shrinkage, employing large blasts (26) would be superior (fig. 9).

This method also has an important application in conjunction with other stoping methods, such as with block caving in boundary cut-off stopes.

Advantages (30).-

1. For mining bodies of strong ore with firm wall rocks the shrinkage method quickly develops and brings the mine into the productive stage, as only a small amount of preliminary development and stope preparation are required. This is particularly advantageous to small companies with limited working capital. (See par. 1, under Disadvantages.)

2. The broken ore in the stopes assists in supporting the walls and eliminates the use of timber for this purpose except as props and stulls may be required to support occasional loose ground.

3. The miners work on a solid floor which provides a sure footing making that feeling of safety and security conducive to efficient work.

4. Rapid working of the stope is possible. A large number of men can often work to advantage in a single stope.

5. Long ore passes extending from level to level are not required, since the ore is drawn from the bottom through a number of chutes or short raises.

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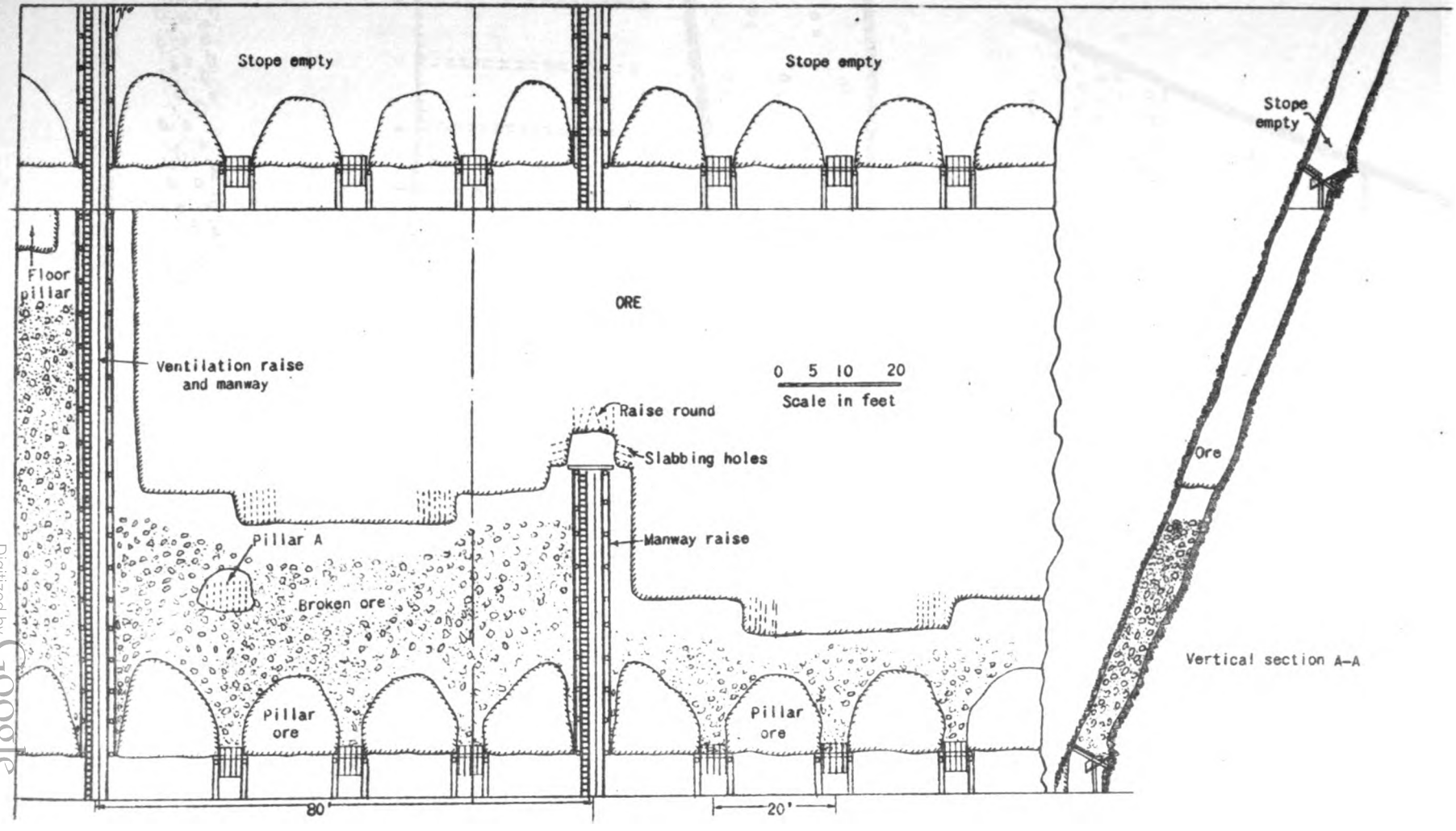

Figure 6.- Longitudinal and vertical section of shrinkage stope.

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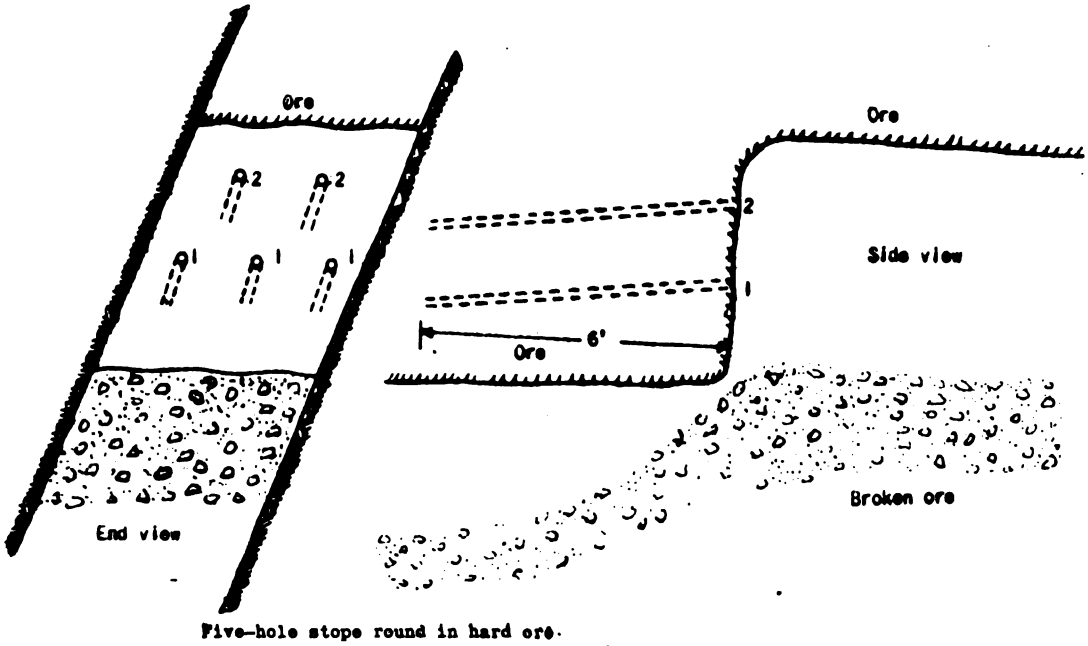
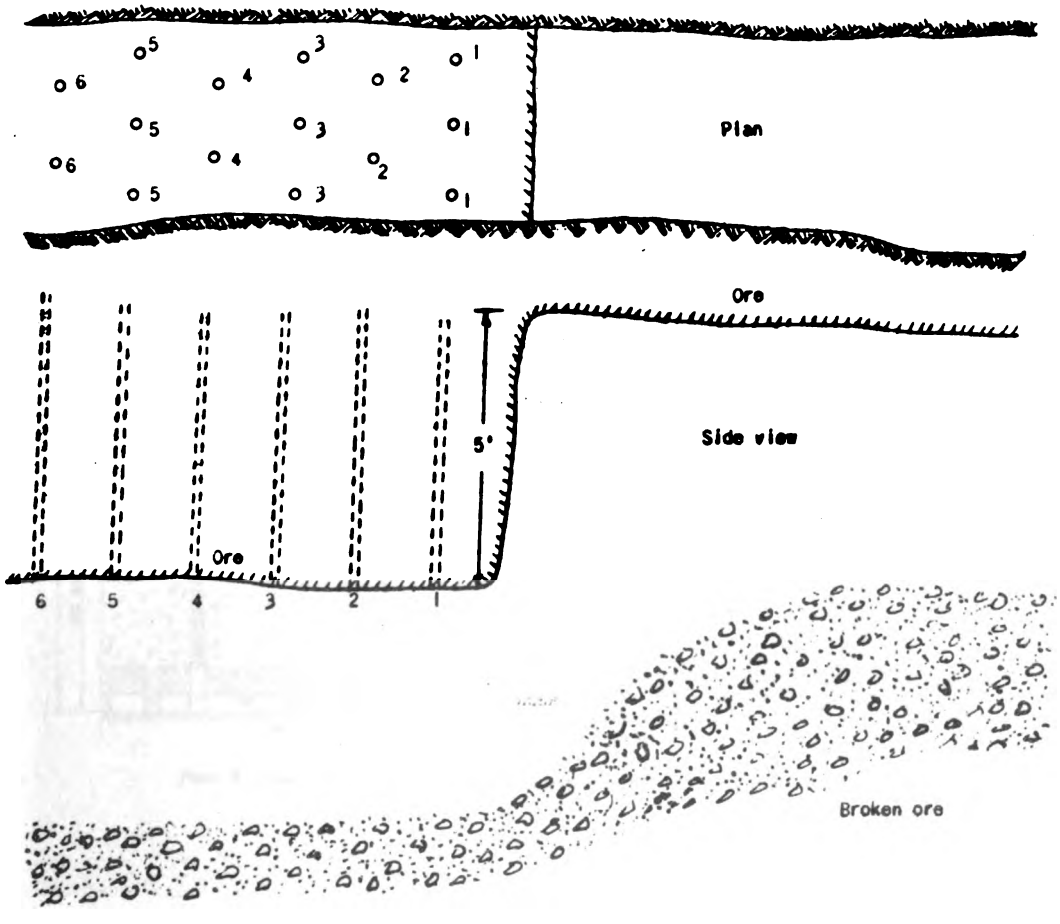


Five-hole stope round in hard ore.



Fifteen-hole stope round in soft ore.

Figure 7.- Stope rounds.

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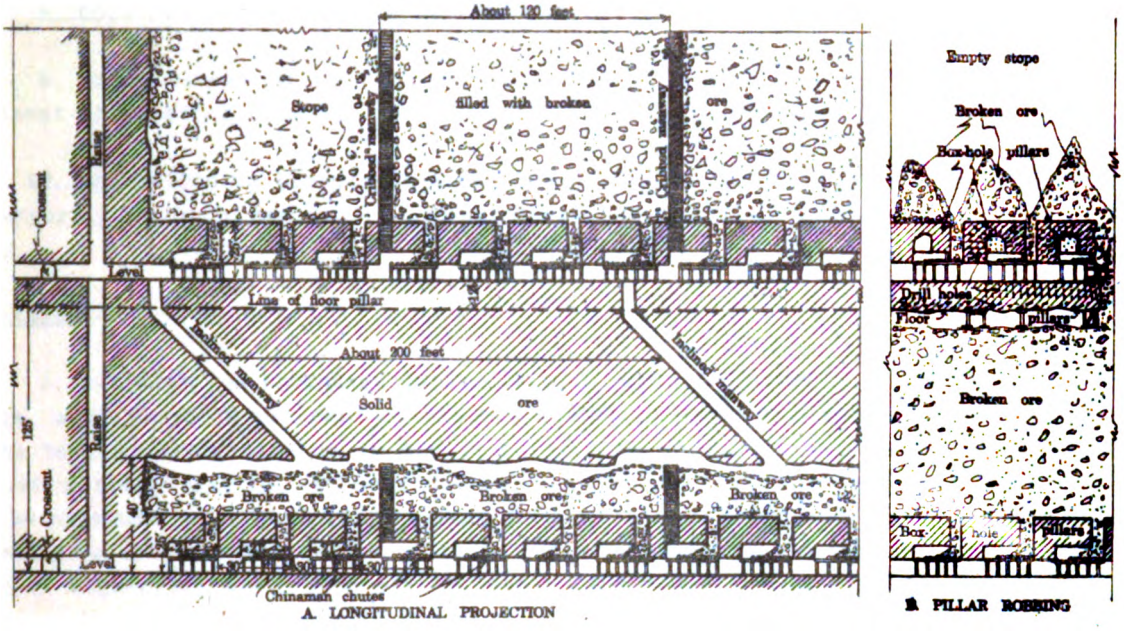

Figure 8. – Shrinkage stoping over box-hole pillars, using chinaman chutes, at Kirkland Lake, Ontario

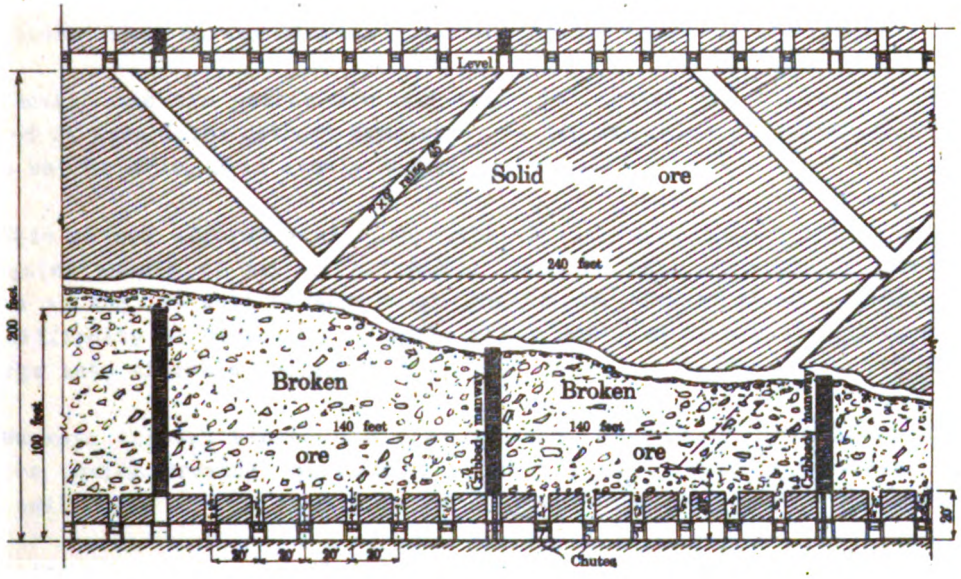

Figure 9. – Shrinkage stoping over box-hole pillars, using stop-board chutes, at Kirkland Lake, Ontario

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6. Tramming or wheeling ore in the stopes is not required.

7. A large reserve of ore is maintained. (See par. 4, under Disadvantages.)

8. Good ventilation can be obtained at little expense.

9. Large blocks of ore can be conveniently broken up in the stopes, thus to a large extent eliminating blasting in the chutes. (See par. 7, under Disadvantages.)

10. The method is cheaper on a per ton of ore basis than cut-and-fill stoping, but not necessarily so on a per unit of metal basis. (See U. S. Bureau of Mines Bull. 306, p. 187.)

Disadvantages.-

1. Although the shrinkage method permits rapid development of a mine to the stoping stage, only about 35 per cent of the ore broken in a given stope is immediately available, the balance being tied up in the stope till it is worked out. For companies having only small working capital, this situation requires that a considerable portion of that capital be expended for advance development work and for breaking ore which can not be turned into cash for a considerable period of time. This disadvantage is particularly important in the case of high-grade ore. (See par. 1, under Advantages.)

2. While the broken ore serves as a support for the walls, if the walls are friable or scaly, considerable contamination of the ore with wall rock may result while the broken ore is drawn, both during stoping and when finally emptying the stope.

3. Though long ore passes are not required, chutes must be more closely spaced than is required in some other methods applicable to the same type of orebodies in order that the broken ore may be drawn down evenly during operation.

4. This method affords little opportunity for sorting lean ore and waste in the stopes. Irregular masses of ore or offsheets from the main vein may be lost. This is especially true in the footwall because these masses are covered up with broken ore or because of the difficulty of disposing of waste which would be broken in following stringers that may enlarge into sizeable bodies in the wall.

5. Manways through broken ore are sometimes difficult to maintain owing to the drag of the ore during drawing, especially in wide veins. This may necessitate driving raises in the wall rocks or in ore pillars for access to the stopes and for ventilation.

6. Although large blocks of ore can be conveniently broken up in the stope (par. 9, under Advantages), large chunks may become covered with dirt and fines and may not be discovered until they give trouble at the chutes.

7. Certain pyritic ores will take fire if left broken in stopes. More often only slight oxidation occurs, but frequently even slight filming of sulphides will result in greatly reduced recovery of the valuable minerals by flotation and may be a serious enough factor to preclude the use of the shrinkage method.

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8. The necessity in some cases of filling the stopes after drawing the broken ore in order to prevent caving of the surface or of overlying veins is common to other stoping methods. As compared to the cut-and-fill method, however, delayed filling after emptying the shrinkage stopes should be cheaper, since it does not usually require that definite amounts of filling material be provided at definite times in order to accommodate stoping operations. With cut-and-fill methods, filling, usually in comparatively small quantities at a time for any given stope, is required promptly and at frequent intervals when the filling cycle of the stoping operation is reached.

9. Travel in shrinkage stopes is often difficult, sometimes being up and down hill between and over draw points. Much time is consumed in moving drills and gear about.

10. Accidents due to sudden subsidence of broken ore sometimes occur in narrow veins where the broken ore hangs up. They can be avoided, however, by proper cooperation between stope bosses and men in opposite shifts.

Results.- Two tables follow, one of which shows results obtained by the shrinkage method for the different metals, in metal yield and man-hours consumed per ton mined at the mines producing over $100,000 in 1929; the other table gives the details of labor, explosives, and power consumption and costs per ton mined at individual mines using this method.

Metal yield and man-hours consumed per ton mined by the shrinkage method at mines producing over $100,000 in 1929

Metal	Number of mines	Tons mined	Yield per ton	Man-hours per ton
Gold	11	5,645,110	0.17 oz.	0.69
Copper	12	2,306,930	33.6 lbs	2.45
Lead-zinc	10	2,011,500	144.4 lbs	2.04
Iron	4	955,900	.456 ton	1.04

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Details of labor, explosives, and power consumption and costs per ton mined at mines using shrinkage-stoping methods

Stoping method	Mine	Ore	Width and dip of orebodies	Labor and supply consumption per ton: Labor, total underground, man-hr.	Explosives, pounds	Timber	Power, kw.h.	Direct mining costs per ton: Development	Stoping	Haulage and hoisting	General underground expense	Surface applicable to underground	Total	Refer I.C. list, p. 36
Shrinkage	Nevada-Massachusetts	W	Av. 4½ ft.; 75°	3.051	1.789	3.63 bd. ft. 0.61 lin. ft.	10.48	$0.907	$2.743	$0.190	$0.105	-	$3.945	(29)
Shrinkage	Black Butte	Hg	15 to 70 ft.; 58°	1.713	1.160	-	18.45	-	-	-	-	-	1.310	(28)
Shrinkage	Teck Hughes	Au	0 to 60 ft.; 75° av.	2.497	2.360	3.52 bd. ft.	19.56	.433	1.557	.443	.202	$0.435	3.070	(32)
Shrinkage	Cortez	Ag	1 to 20 ft.; 45 to 80°	3.362	3.300	2.27 bd. ft.	21.18	1.427	1.972	.467	-	-	3.866	(33)
Shrinkage	Engels	Cu	100 ft.; 80°	1.535	2.758	1.23 bd. ft. 0.074 lin. ft.	9.64	.479	.760	.438	-	-	1.677	(27)
Shrinkage	Michigan D	Cu	3.5 to 20 ft.; 56°	1.239	.983	0.805 lin. ft.	-	.218	.482	.556	.240	-	1.496	(20)
Shrinkage	Kirkland No. 2	Au	8 to 40 ft.; 75 to 85°	1.858	1.624	1.67 bd. ft. 0.59 lin. ft.,	-	1.450	2.210	.830	-	-	4.490	
Shrinkage	Kirkland No. 4	Au	3 to 20 ft.; av. 60°	2.810	2.270	0.864 lin. ft.	23.00	-	-	-	-	-	-	
Shrinkage	Porcupine No. 1	Au	4 to 40 ft.; 45 to 90°	2.740	2.210	0.42 bd. ft. 0.70 lin. ft.	32.22	.790	-	-	-	-	-	
Shrinkage	Porcupine No. 2	Au	6 to 60 ft.; steep dips	2.700	1.277	1.39 lin. ft.	20.81	.850	(2.270		.200	.090	3.210	
Shrinkage, square-set, and caving	Homestake	Au	25 to 250 ft.; 70°	1.161	.753	4.87 bd. ft.	10.00	.130	1.143	.320	.191	-	1.784	
Modified shrinkage and caving	Alaska-Juneau	Au	Wide	.266	.400	-	1.61	.061	.122	.114	-	-	.297	(26)
Shrinkage with pillar caving	Michigan Iron	Fe	Max. 140 ft.; 70°	.595	.501	3.24 bd. ft. 0.544 lin. ft.	4.36	-	-	-	-			
Semishrinkage	Marquette No. 4	Fe	5 to 40 ft. thick; 30 to 35°	1.130	.904	0.006 lin. ft.	12.34	.212	.801	.205	.053	.009	1.280	(35)
Shrinkage; some cut-and-fill	Eighty-Five, New Mexico	Cu	2 to 10 ft. thick; av. 80°	6.230	-	-	96.25	-	1.970	1.140	1.170	.210	4.490	(36)
Shrinkage	Verde Central	Cu	5 to 100 ft. thick	1.670	1.160	3.08 bd. ft.	16.44	-	1.661 incl. stope development	.580	.111	.033	2.385 development excluded	(37)

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Cut-and-Fill Method

Cut-and-fill stoping has long been used in many parts of the world to mine bodies of ore with too weak to stand for any length of time unsupported and where it has been necessary or desirable to prevent caving of the ground and subsidence of the surface. It has been widely used in Europe for many years.

By this method (45 to 51) the ore is stoped upward from the level by a series of flat or inclined slices (figs. 10, 11, and 12). After each slice is taken, the broken ore is removed and waste filling is run in to within a few feet of the solid back. The miners then stand on this waste material in making the next cut. A regular cycle of operations is carried out: Breaking; removal of broken ore; and filling; and then the cycle is repeated.

Application.- Cut-and-fill stoping is usually applied to the mining of medium to high grade vein or bedded deposits of moderately strong to strong ore having dips of 55° or more and where one or both walls are relatively weak.

The ore must stand well over moderate spans for a short time. This method is also applied to wide, thick bodies of hard, high-grade ore by mining stopes separated by pillars which are later removed by the same or other methods. It is also used instead of shrinkage stoping where it is desired to extract the ore at once rather than to leave it in the stopes for the considerable periods necessitated by the use of the shrinkage method.

Advantages.-

1. Bad walls may be safely held and the general stability of the mine maintained by the filling.

2. Irregular ore bodies can be easily and completely mined and offshoots or tongues of ore in the walls can be followed, leaving broken waste in the stope. The ore body may be prospected as stoped to some extent.

3. Horses of lean or barren rock can be left unbroken and waste can be sorted out from the broken ore and left in the stope.

4. There is less dilution than with shrinkage stoping.

5. Secondary breaking (bulldozing) can be done in the stope, and all material put in the chutes can thus be prepared for easy drawing and handling.

6. The accident rate is lower than for shrinkage stoping and square-setting.

7. The broken ore is removed as fast as broken, so that large capital sums need not be tied up in broken ore reserves.

8. Stopes are easily ventilated.

Disadvantages.-

1. The rate of output from the stope is limited or else is irregular due to stopping the breaking of ore during filling operations.

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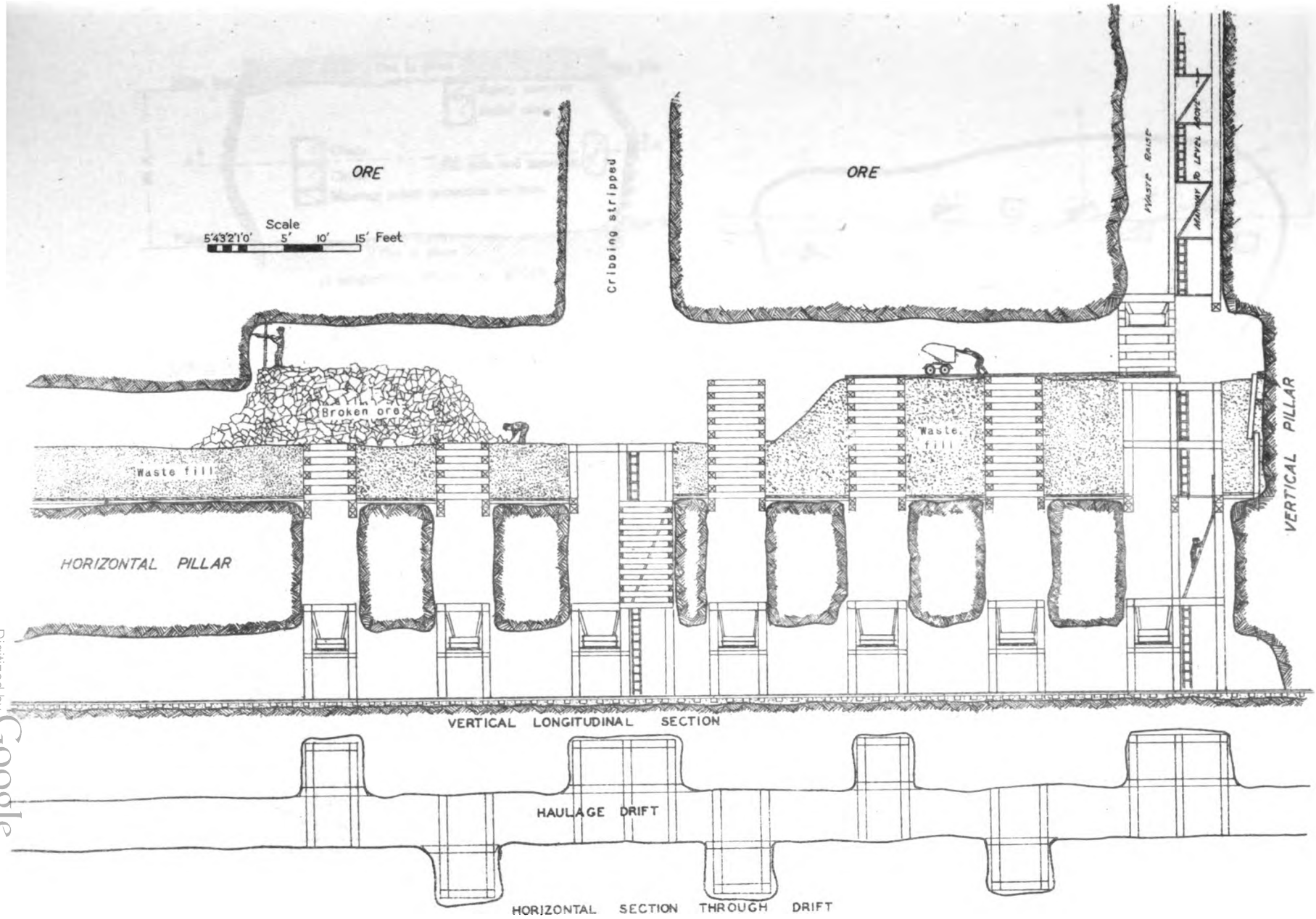

Figure 10– Typical cut-and-fill stope

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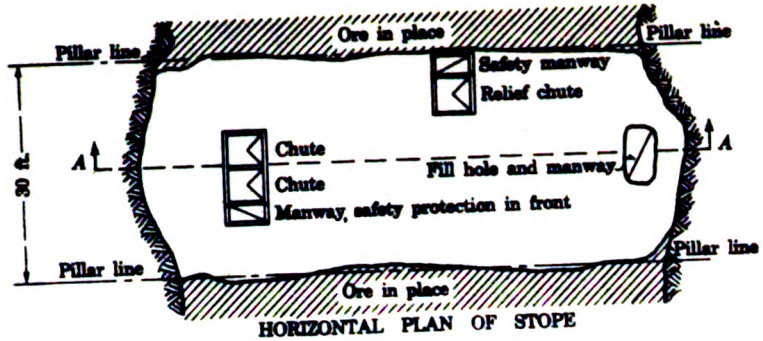
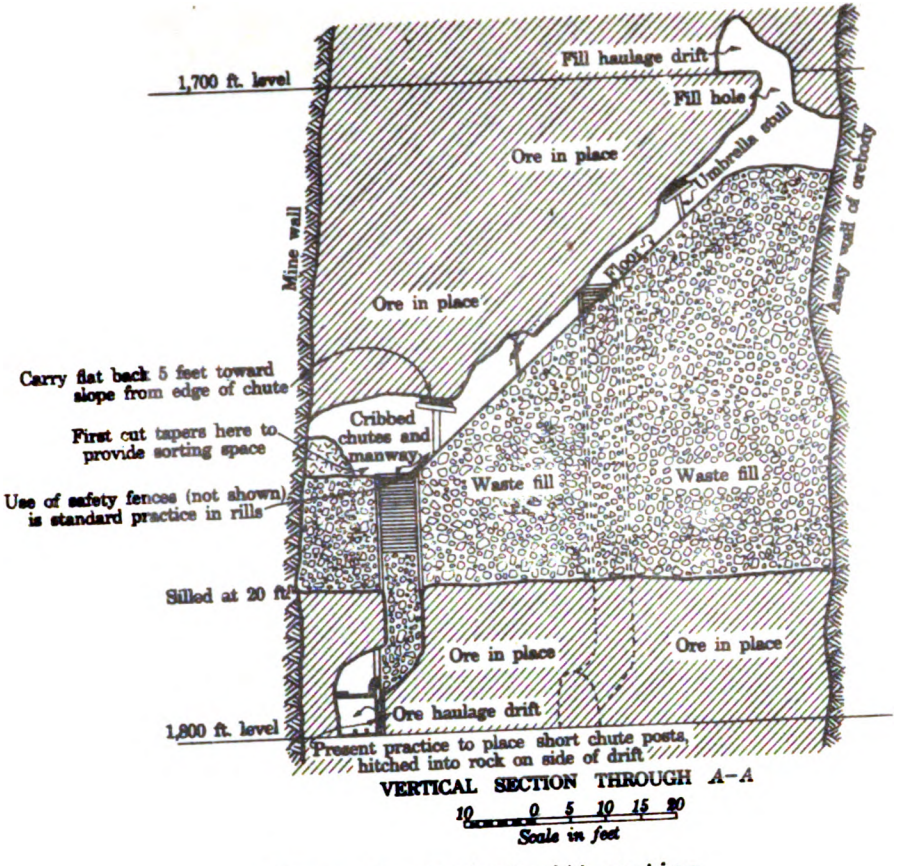


HORIZONTAL PLAN OF STOPE

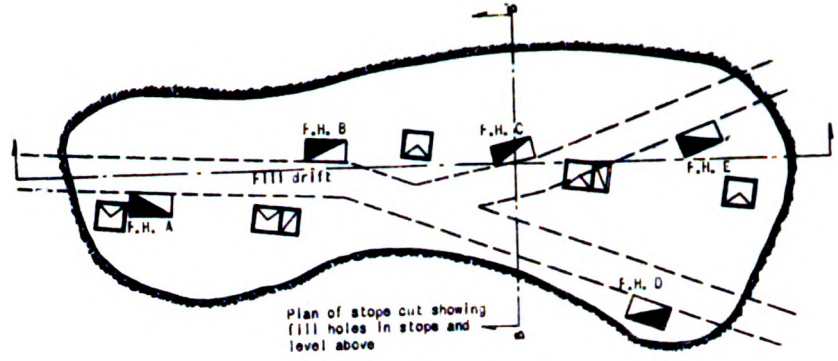

1,700 ft. level
Fill haulage drift
Fill hole
Ore in place
Umbrella stull
Mine wall
Floor
Ore in place
Away wall of orebody
Carry flat back 5 feet toward slope from edge of chute
First cut tapers here to provide sorting space
Cribbed chutes and manway
Waste fill
Waste fill
Use of safety fences (not shown) is standard practice in rills
Silled at 20 ft.
Ore in place
Ore in place
Ore haulage drift
1,800 ft. level
Present practice to place short chute posts, hitched into rock on side of drift

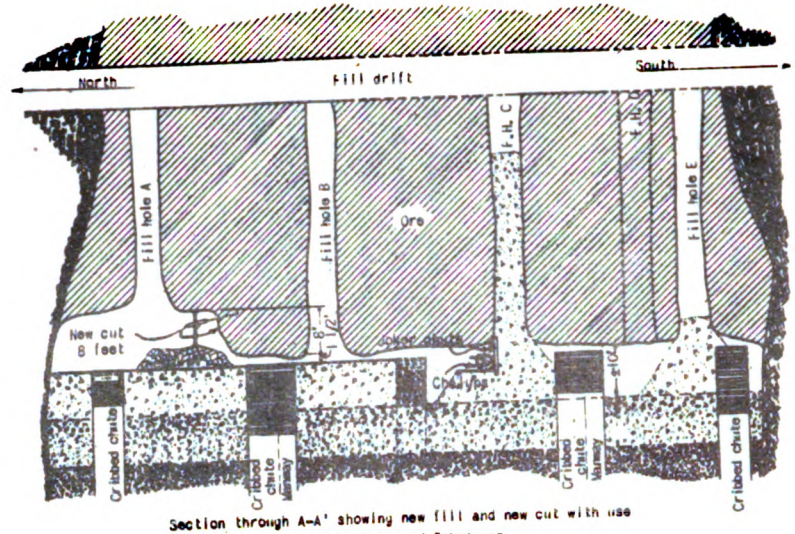
VERTICAL SECTION THROUGH *A–A*

10 0 5 10 15 20

Scale in feet

Figure 11.– Typical rill section





Section through A–A' showing new fill and new cut with use of joker chute and "chaiupa"

Figure 12.– Typical cut-and-fill stope in operation

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2. Filling must be provided at such times and in such quantities as are required to maintain a regular cycle of stope operations.

3. Cost is higher per ton of ore mined than for shrinkage stoping but is usually lower than for square-setting.

4. Handling cost of ore and waste in stopes is often high, or else ore and waste passes are installed at such close intervals that their cost is great.

Results.- Two tables are given; one shows the different metals, the metal yield and man-hours consumed per ton mined by the cut-and-fill method at mines that produced over $100,000 in 1929; the other gives details of labor, explosives, and power consumption and costs per ton mined at individual mines using this method.

Metal yield and man-hours consumed per ton mined by cut-and-fill methods at mines producing over $100,000 in 1929

Metal	Number of mines	Tons mined	Yield per ton	Man-hours per ton
Gold	2	13.150	1.03 oz.	15.78
Copper	6	1,573,135	67.5 lbs.	4.18
Iron	2	272,835	.550 ton	2.25
Lead-zinc	11	664,252	161.72 lbs.	5.48

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Details of labor, explosives, and power consumption and costs per ton mined at mines using cut-and-fill methods

Stoping method	Mine	Ore	Width and dip of orebodies	Labor and supply consumption per ton				Direct mining costs per ton						Reference, I.C. list, p. 36
				Labor, Total underground, man-hr.	Explosives, pounds	Timber	Power, kw.h.	Development	Stoping	Haulage and hoisting	General underground expense	Surface applicable to underground	Total	
Cut-and-fill	Matahambre	Cu	20 to 30 ft.; 42 to 45°	4.310	1.020	1.146 bd. ft. 0.148 pos. props	14.01	$0.711	$1.267	$0.388	$0.184	$0.019	$2.569	(45)
Cut-and-fill, some square-sets, top slicing and shrinkage	Pilares	Cu	Various; steep	3.790	.383	5.71 lin. ft.	6.20	.300	1.260	Included with development and mining	1.110	-	2.670	(48)
Cut-and-fill, and square-set	Pecos	Pb, Zn Cu	Narrow stringers to 40 ft.; nearly 90°	5.674	.730	3.90 lin. ft.	11.78	1.218	2.396	.711	.563	.010	4.898	(49)
Cut-and-fill	Michigan E	Cu	3.5 to 20 ft.; 70°	3.625	.647	3.22 bd. ft.	8.19, plus 70 lbs. coal	.598 (haulage included)	1.765	.158 hoisting only	-	-	2.699	(20)
Inclined cut-and-fill, and semishrinkage	Campbell (C & A)	Cu	50 to 250 ft.; 25 to 90°	-	$0.12 per ton	$0.175 per ton	-	-	1.280	-	-	-	-	(47)
Cut-and-fill, 64% Square-set, 27% Top slicing, 8% Shrinkage, 1%	United Verde	Cu	Large	2.7 approx.	.55	6.95 bd. ft.	-	-	1.148	.238	1.037	.122	2.544	(50)
Cut-and-fill	Block P Mine	Pb, Zn	1 to 4 ft.; 65 to 88°	5.350	2.850	3.95 bd. ft. 1.30 lin. ft.	17.45	-	-	-	-	-	-	(51)

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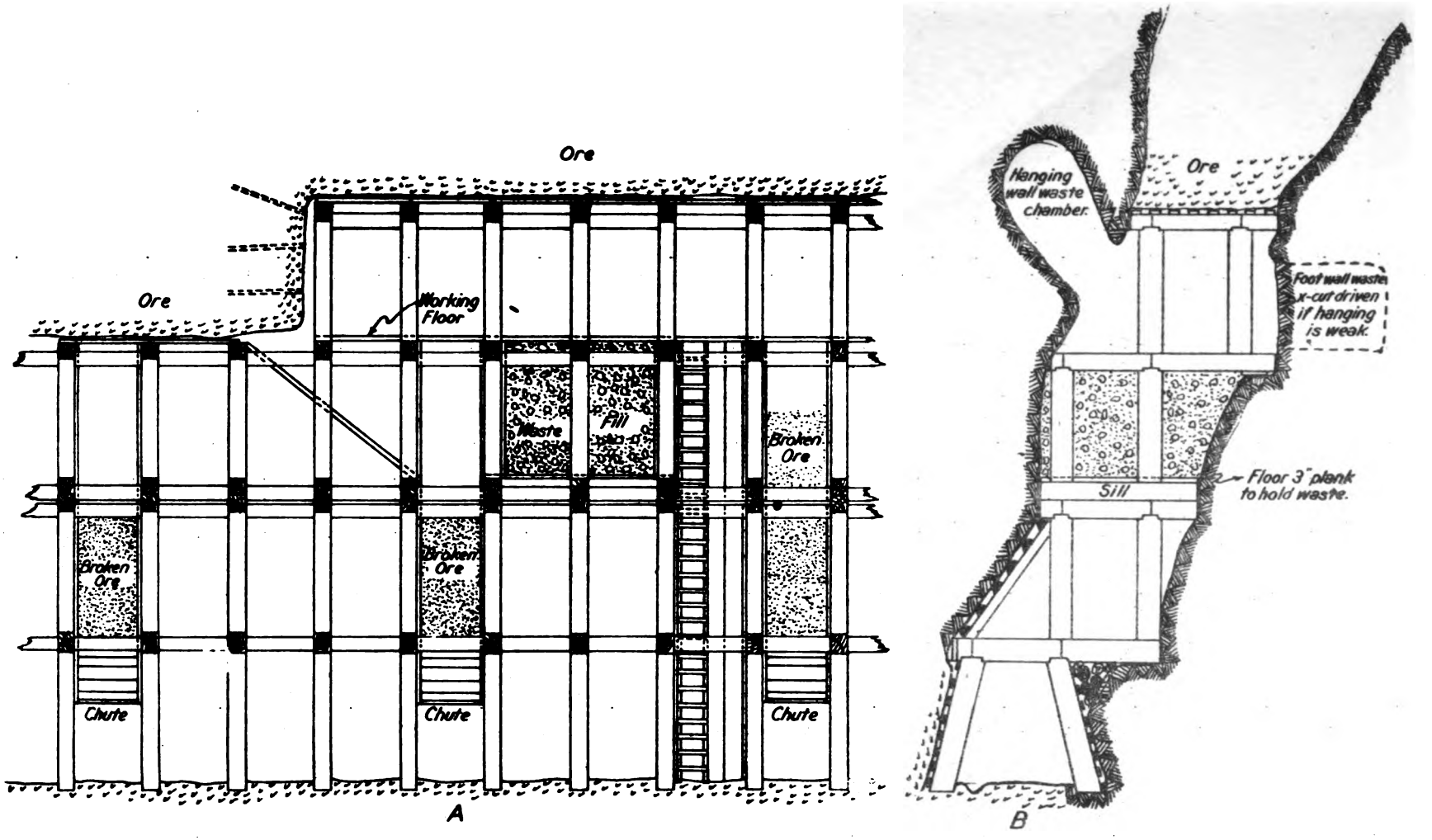

Figure 13 - Vertical sections of stope.
A: Longitudinal section. B: Cross-section.

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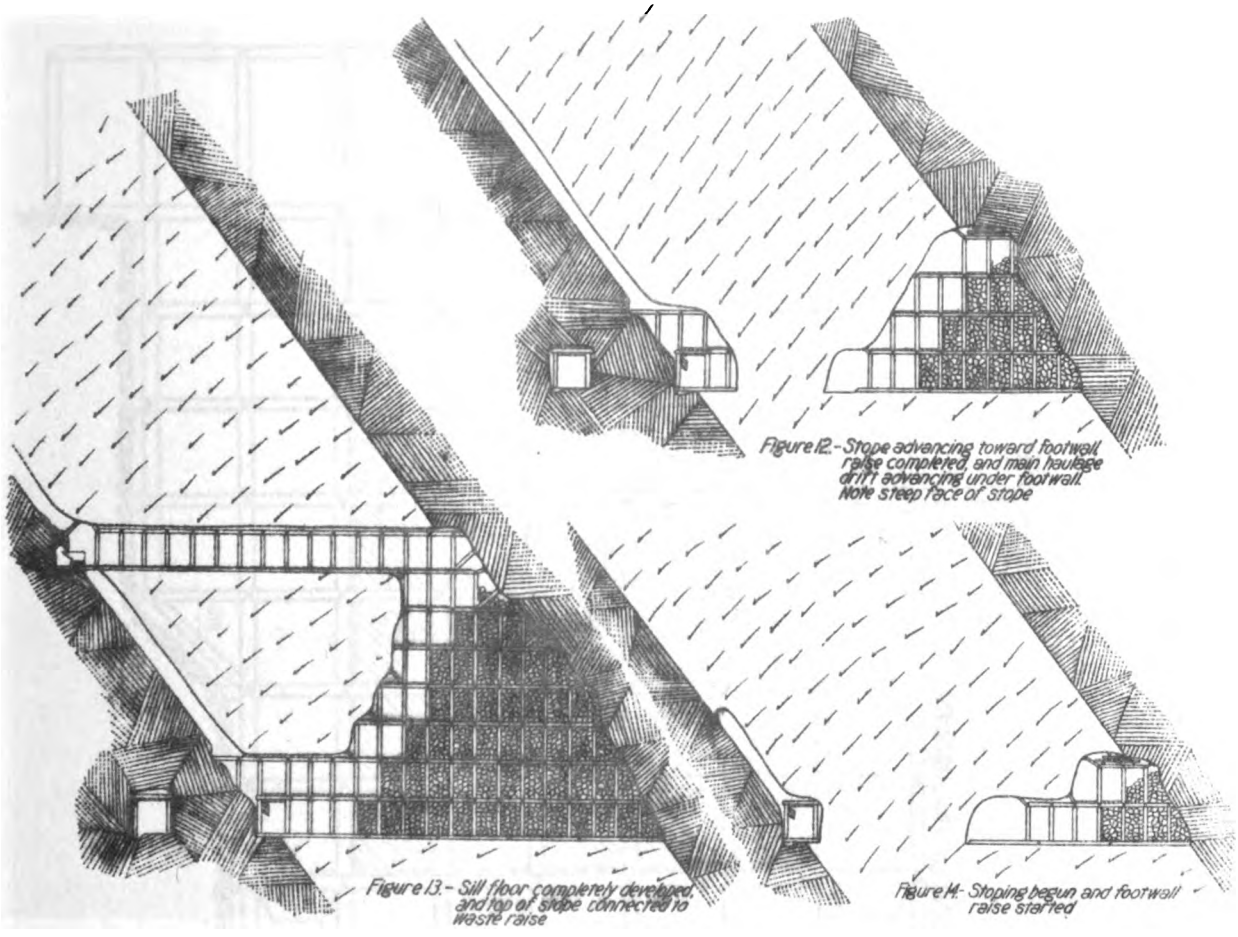
Figure 12.- Stope advancing toward footwall, raise completed, and main haulage drift advancing under footwall. Note steep face of stope
Figure 13.- Sill floor completely developed, and top of stope connected to waste raise
Figure 14.- Stoping begun and footwall raise started

Figure 14.- Progressive development of stope with square-sets at mine in Tintic District, Utah

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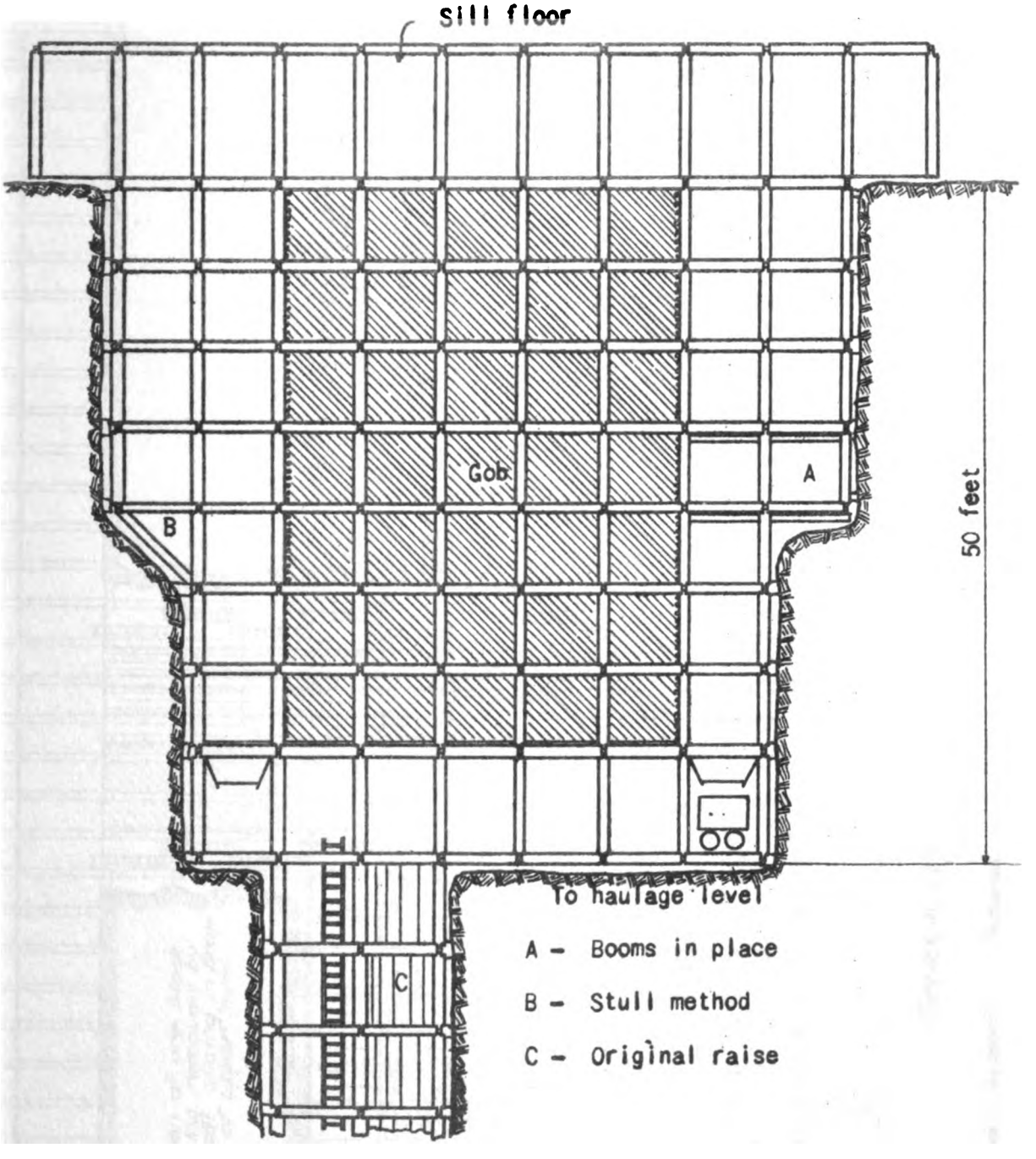

Figure 15.- Section showing underhand stopes

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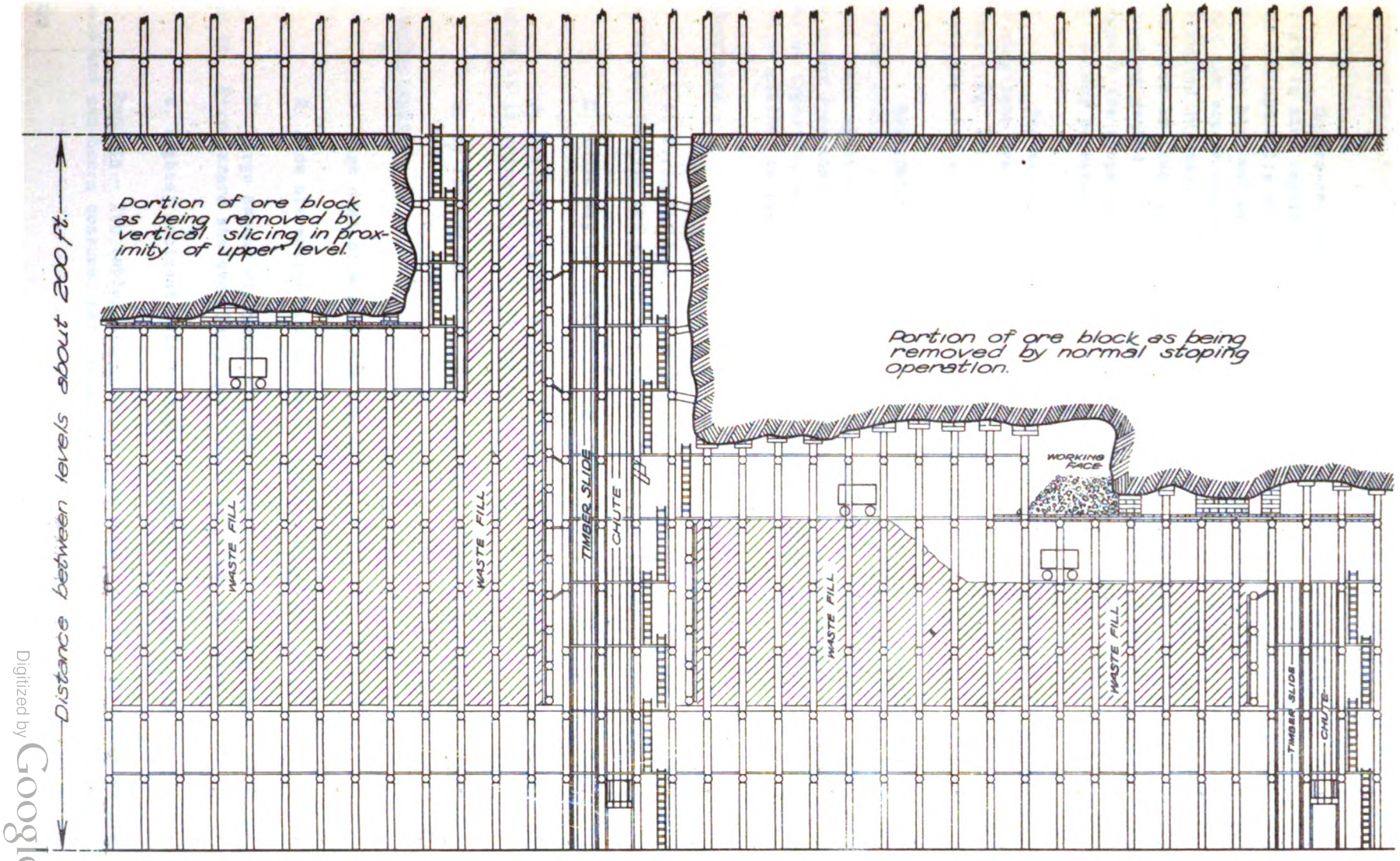
Distance between levels about 200 ft.
Portion of ore block as being removed by vertical slicing in proximity of upper level.
Portion of ore block as being removed by normal stoping operation.
WASTE FILL
WASTE FILL
TIMBER SLIDE
CHUTE
WORKING FACE
WASTE FILL
WASTE FILL
TIMBER SLIDE
CHUTE

GENERALIZED SKETCH SHOWING METHOD OF STOPE MINING AS PRACTICED AT THE HECLA MINE

0 5 10 20 30 40

FIGURE 11

Note: Girts not shown in sketch.

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Square-Set and Stull-Set Stoping Methods

Square-set stoping has been employed for many years and in widely separated districts to mine regular and irregular deposits of ore of appreciable vertical dimension where the ore and walls will not stand without immediate support except over very small spans and where the back and walls must be artificially supported against caving. Some engineers claim that the square set method was first used on the Comstock Lode. In this method the ore is excavated in small, rectangular blocks, one block at a time. After each block is removed, its place is taken by a set of framed timber which serves as a temporary support to the surrounding ground. As best employed to-day, square-set timbering is not used to permanently support the stope nor can it hold great pressures, but as soon as possible waste filling is put in for permanent support.

The method is commonly employed for stoping upward from the level (fig. 13) but is sometimes used for mining laterally from a raise (fig. 14) or less often downward from a level (fig. 15). Where the walls and orebody itself are sufficiently strong, stull-sets are sometimes used in place of square-sets (fig. 16).

Application.- Square-set or stull-set stoping is applicable to the mining of irregular bodies of high-grade ore too weak to stand long without artificial support, even over small spans and with weak walls which require filling to support them and which can not be mined from the top downward due to the necessity of permanently supporting the back. It has an important application as an auxiliary to other methods as, for example, the mining out of pillars between filled stopes.

Advantages.-

1. Irregular ore bodies may be worked, leaving horses of waste or lean ore in place, and tongues and off-shoots of ore may be followed.

2. Waste may be sorted out in the stopes and ore dilution reduced to a minimum.

3. Control of grade of ore is easy, since each new face can be sampled and assayed before it is necessary to drill the face.

4. By filling the sets, only a small amount of ground need stand open at a time.

Disadvantages.-

1. High cost of mining per ton of ore.

2. Slow ore extraction and small tonnage mined per man-shift.

3. Large amount of timber required, cost of timber and labor of framing and placing it. Fire hazard wherever large quantities of timber are used.

4. Highest accident rate of any underground stoping method.

Results.- Two tables are given; one to show, for the different metals, the metal yield and man-hours consumed per ton mined by the square-set and stull-set stoping methods

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at mines that produced over $100,000 in 1929; the other to give the details of labor, explosives, and power consumption and costs per ton mined at individual mines using this method.

Metal yield and man-hours consumed per ton mined by square-set and stull-set stoping methods at mines producing over $100,000 in 1929

Metal	Number of mines	Tons mined	Yield per ton	Man-hours per ton
Gold	7	379,022	0.35 oz.	5.35
Copper	26	4,318,294	92 lbs.	4.95
Iron	0	0	0	0
Lead-zinc	28	3,121,746	-	5.45

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Details of labor, explosives, and power consumption and cost per ton at mines using square-set stoping methods

Stoping method	Mine	Ore	Width and dip of orebodies	Labor and supply consumption per ton: Labor, total underground, man-hrs	Explosives, pounds	Timber	Power, kw.h.	Direct mining costs per ton: Development	Stoping	Haulage and hoisting	General underground expense	Surface applicable to underground	Total	Refer I.C. list, p. 36
Square-set	Magma	Cu	20 to 30 ft.; 45 to 80°	4.260	0.900	19.0 bd. ft.	34.61	$0.736	$2.849	$0.616	$1.166	$0.130	$5.497	(55)
Square-set	U.V.X.	Cu	Wide bodies; steep	3.236	-	18.5 bd. ft.	-	.676	1.894	.508	.474	-	3.552	(56)
Square-set	Park-Utah	Pb, Zn, Ag	3 to 80 ft.; 40 to 55°	3.540	1.530	16.5 bd. ft.	29.23	.828	2.426	.282	.583	.543	4.662	(57)
Square-set	Argonaut	Au	Av. 20 ft., max. 65 ft; 63°	4.168	1.010	7.05 bd. ft. 1.08 lin. ft.	33.08	.165	2.439	.519	.577	.291	3.991	(58)
Square-set	Tintic Standard	Pb, Ag	Wide bodies; 45 to 90°	7.255	1.068	25.5 bd. ft.	46.60	1.143	4.973	1.158	.322	.783	8.379	(59)
Square-set	Silver King	Pb, Zn, Au, Ag		8.055	3.607	(?)	77.70	2.086	3.502	1.848	.309	-	7.745	(61)
Square-set	Page	Pb, Zn, Ag	Max. 20 ft.; 40 to 60°	2.758	1.405	13.09 bd. ft.	15.07	1.170	2.150	.160	.180	.160	3.820	(62)
Square-set; cut-and-fill	Ground Hog	Pb, Zn, Cu	3 to 25 ft.; av. 50°	4.758	.630	9.00 bd. ft.	8.75	1.393	1.762	.628	.080	.127	3.990	(63)
Square-set	Black Rock	Pb, Zn, Cu, Au, Ag	Stopes 6 to 70 ft.; av. 80°	6.683	1.730	12.0 bd. ft. 2.8 lin. ft.	53.70	-	-	-	-	-	-	(60)
Square-set	Bunker Hill and Sullivan	Pb, Ag	Up to 40 ft.; 40 to 50°	3.705	$0.167 per ton	$0.321 per ton	$0.188 per ton	$11.43 per ft	2.361	distributed	distributed	distributed	3.897	(64)
Stull and post sets with fill; some shrinkage	Hecla and Star	Pb, Zn, Ag	3 to 40 ft.; 70 to 80°	2.640	0.783	11.207 bd. ft. 1.234 lin. ft	10.97	.638	1.211	.322	.766	.360	3.297	(70)
Stull and post sets with fill	Morning	Pb, Zn, Ag	6 to 30 ft.; 80 to 90°	3.129	.964	12.753 bd. ft.	39.37	.442	2.371	.530	.698	.204	4.245	(71)

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Caved-Stope Methods

The caved-stope method is used where the overlying rock or capping of the orebody is too weak to form a roof that can be supported by pillars as in the open-stope method, and where permanent support of the roof or surface is not necessary. No attempt is made to support this capping, which is allowed to cave as the extraction of the ore proceeds directly beneath it. Under caved stopes, we have three principal subdivisions; two of them are distinctly different methods of stoping and the other is a combination of these two.

First, we have top slicing (77), in which the ore is broken by drilling and blasting, and after its removal from the stope the capping or overburden is caved. In this method, mining starts at the top of the ore body and advances progressively downward, each successive slice being mined out right up to the cave above it.

Second, we have the block-caving method (103) in which the ore is undercut at a considerable distance below the capping and is broken up by caving action induced by the force of gravity, both broken ore and capping moving downward in a mass as the broken ore is drawn off from below.

The third method is termed "sublevel caving" (77). In this method mining starts near the top of the ore body, and slices are taken similar to those driven in top slicing; however, instead of spacing the levels so that each slice is mined up to the cave above, the vertical interval is made greater, the slice being driven at ordinary drift height to the stope limit, and the back of ore over the slice and under the cave is broken down on the retreat by caving, assisted to some degree by light blasts. This method thus resembles top slicing in two respects and block caving in another, but it can not, strictly speaking, be classed with either one.

Top slicing probably originated in the iron mines in the north of England and was first applied in this country, as far as is known, at the Lake Angeline mine, Ishpeming, Mich., some 50 years ago, by Capt. Thomas Walters. It has found its widest application in this country in the iron mines of the Lake Superior region and is the standard method of underground mining on the Mesabi range.

Sublevel caving was probably developed from top slicing and is the type method employed on the Gogebic range, in Michigan.

Block caving was early employed, at least as far back as the nineties, at the Pewabic mine on the Menominee range in Michigan, and later at the Tobin mine. It was later applied in Utah and subsequently at the porphyry copper deposits of Arizona (100 to 104) and Nevada, where it has reached its highest efficiency and found its greatest use. The method is also employed in Chile (105) at the Andes Copper Co.'s mine and is to be applied at Mt. Isa in Queensland.

Results.- Four tables are given; one shows, for the different metallic ores, the metal yield and man-hours consumed per ton mined by caved-stope methods at mines that produced over $100,000 in 1929; the others give the details of labor, explosives, and power consumption and costs per ton mined at individual mines using sublevel-caving, top-slicing, and block-caving methods.

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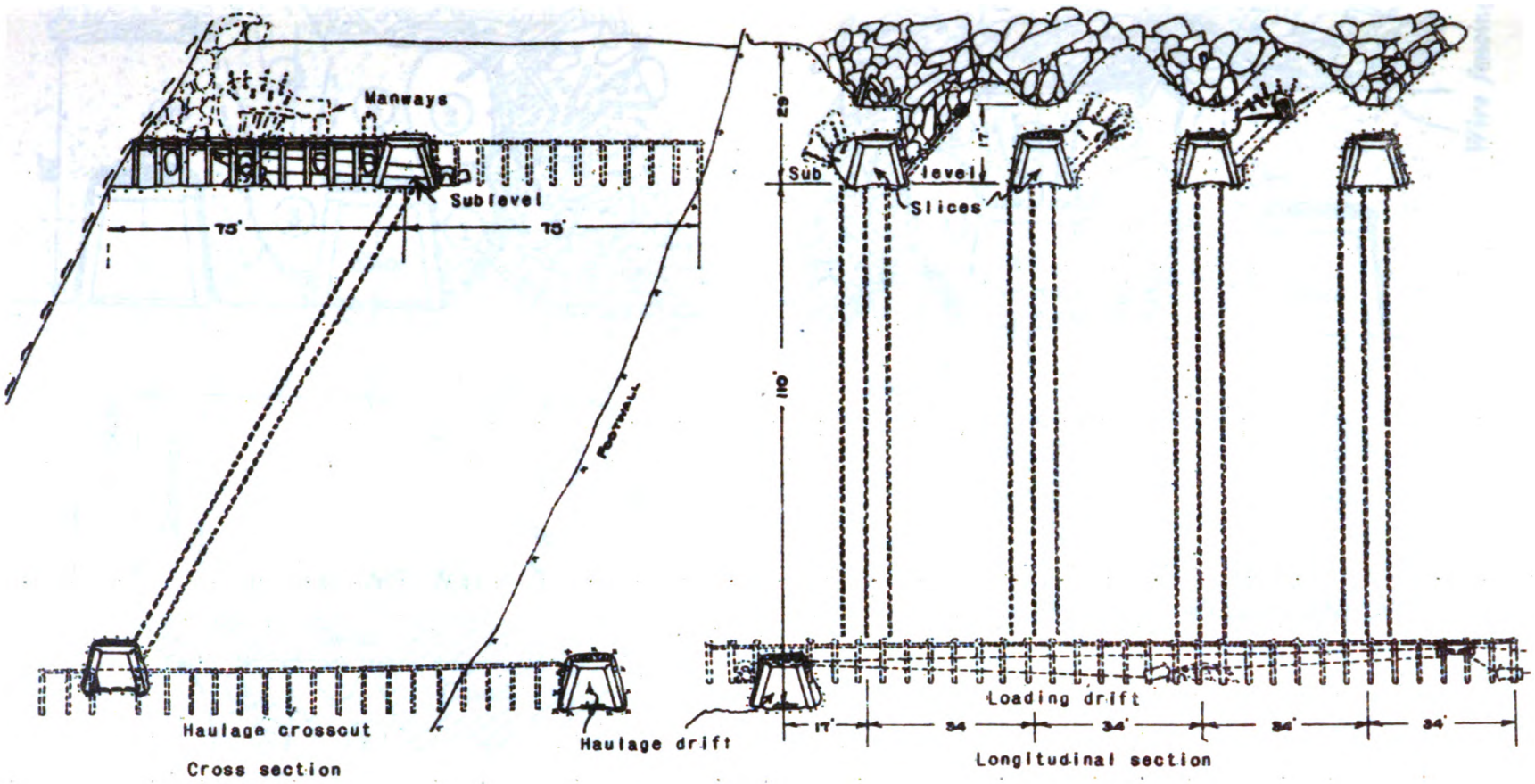

Figure 17.- Sublevel caving with scraper loading drift

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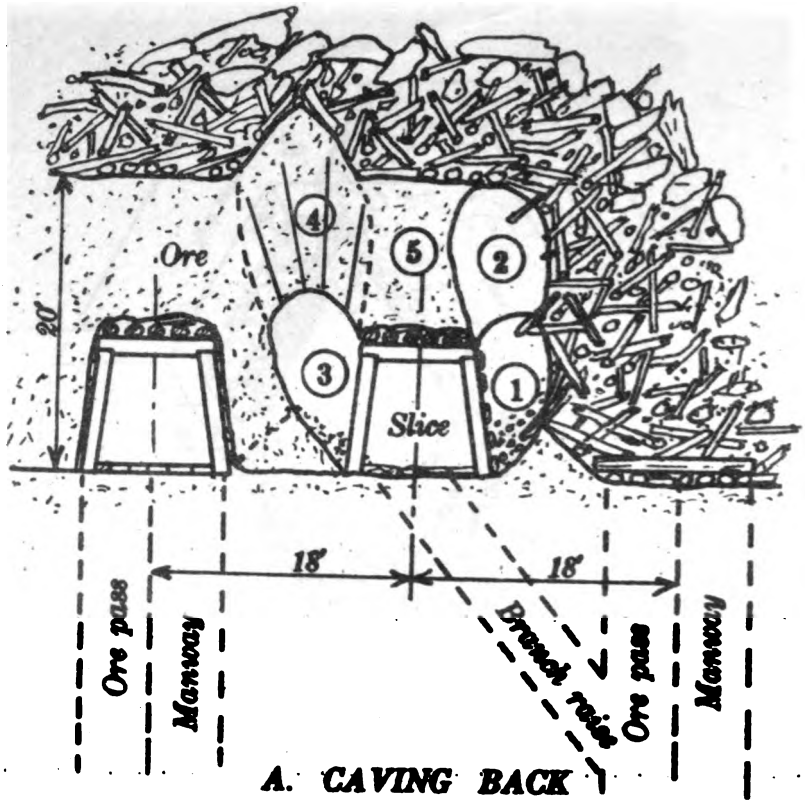
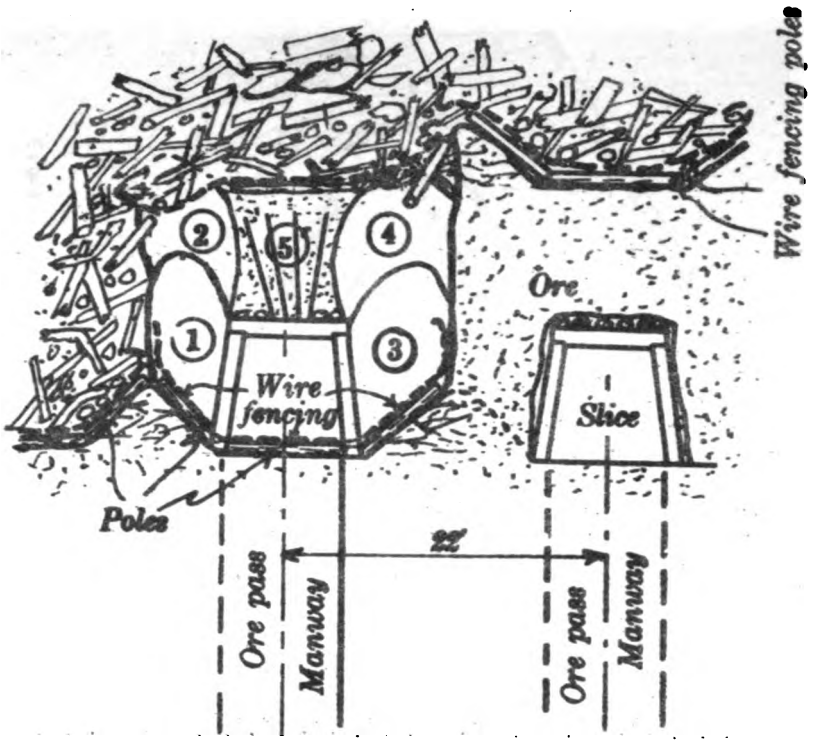
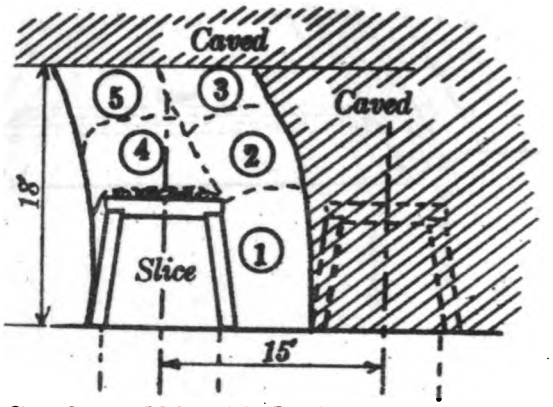


A. CAVING BACK



B. POLES AND WIRE FENCING



C. CAVING ONE SIDE ONLY

Figure 18 – Cross sections showing "caving back" operation

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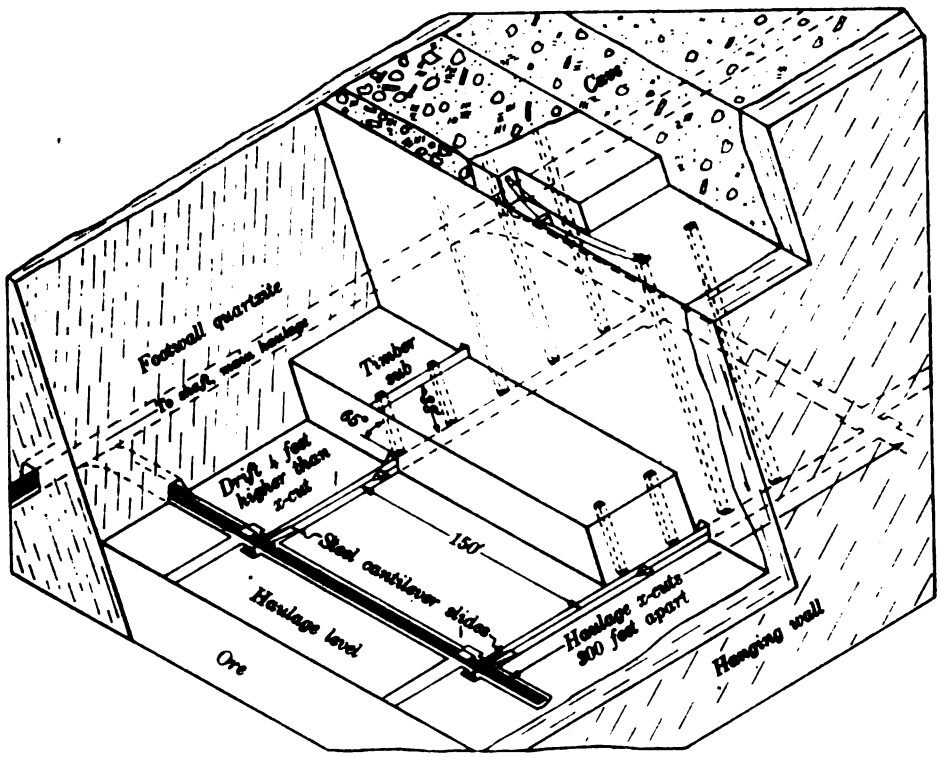

Figure 19.- Sublevel caving method of mining using scrapers

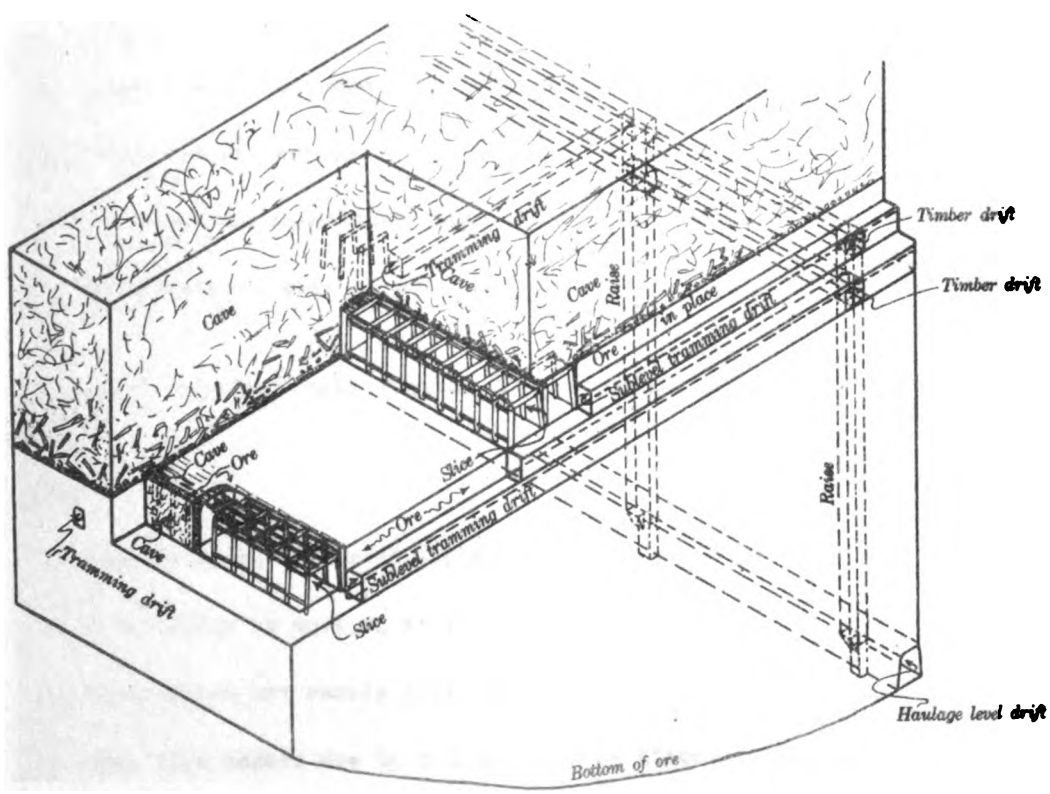

Figure 20.- General scheme of horizontal top slicing using sublevel tramming drifts

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Metal yield and man-hours consumed per ton mined by caved-stope methods at mines producing over $100,000 in 1929

Metal	Number of mines	Tons mined	Yield per ton	Man-hours per ton
Gold	0	0	0	0
Copper[3]	7	18,576,196	18.6 lbs.	0.63
Lead-zinc	0	0	0	0
Iron[1]	37	14,200,257	.520 ton	1.05
Iron[2]	17	6,521,407	.529 ton	1.06

1/ Top slicing; 2/ sublevel caving; 3/ block caving.

Sublevel Caving (77, 90, 17)

Application.- Sublevel caving is applicable to the mining of low to medium grade steeply dipping bodies of fairly weak and moderately soft ore inclosed in walls of weak to medium strength and under a moderately weak but hard capping which will cave in large blocks. Ore bodies may be wide or narrow. The conditions required are similar to those for top slicing except that for top-slicing the capping must break fairly small and cave immediately the support is removed and fill the excavation tightly, whereas for sublevel caving the capping should hang for a short time over small spans while the caved ore is being removed (figs. 17, 18, 19). Obviously it must be permissible to cave the surface.

Advantages.-

1. Low cost per ton for mining heavy ground.

2. Lower timber cost and less stope development per ton than for top slicing.

3. Rapid ore extraction.

4. Under certain conditions, high percentage of extraction and very littl dilution.

5. Applicable to ores of more or less wet and sticky nature not suited to block caving.

6. Lowest accident rate (United States mines, 1929) of any of the underground stoping methods.

Disadvantages.-

1. More dilution than with top slicing and square-setting.

2. Practically no sorting in stopes possible.

3. Ventilation not easily provided.

4. Some fire hazard due to accumulation of timber in the gob.

5. Low grade or "Junore" in capping and marginal areas is lost.

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Details of labor, explosives, and power consumption and costs per ton mined at mines using sublevel-caving methods

Stoping method	Mine	Ore	Width and dip of orebodies	Labor and supply consumption per ton: Labor, total underground, man-hrs	Explosives, pound	Timber	Power, kw.h.	Direct mining costs per ton: Development	Stoping	Haulage and hoisting	General underground expense	Surface applicable to underground	Total	Reference I.C. list p.
Sublevel caving	Montreal	Fe	Scattered bodies, narrow to wide; 65°	1.336	0.590	2.76 bd. ft.	6.24 plus 32 lbs. coal	$0.254	$0.360	$0.344	$0.311	$0.070	$1.399	(17
Sublevel caving	Eureka	Fe	5 to 20 ft. up to wide bodies; 55 to 75°	1.397	.710	3.35 bd. ft.	15.62	.317	.398	.408	.414	-	1.537	(93
Sublevel caving	No. 16	Fe	10 to 175 ft.; 65°	1.193	.421	1.55 bd. ft. 0.0013 cords lagging	-	-	-	-	-	-	-	-
Sublevel caving	No. 20	Fe	110 ft.; 65°	.971	.697	(?)	9.38	-	-	-	-	-	-	-

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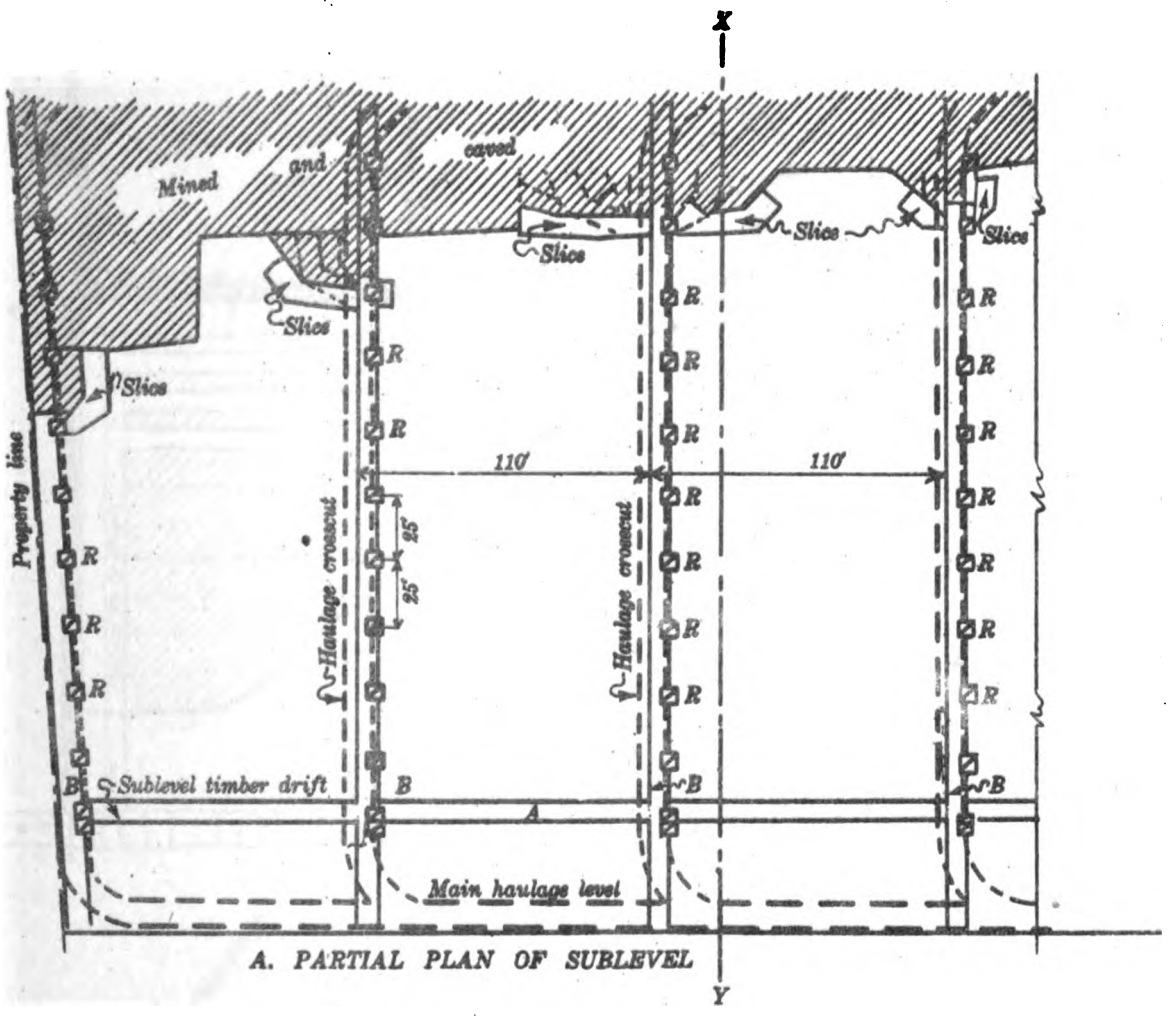

Figure 21 – Radial top slicing to chutes; thick ore body

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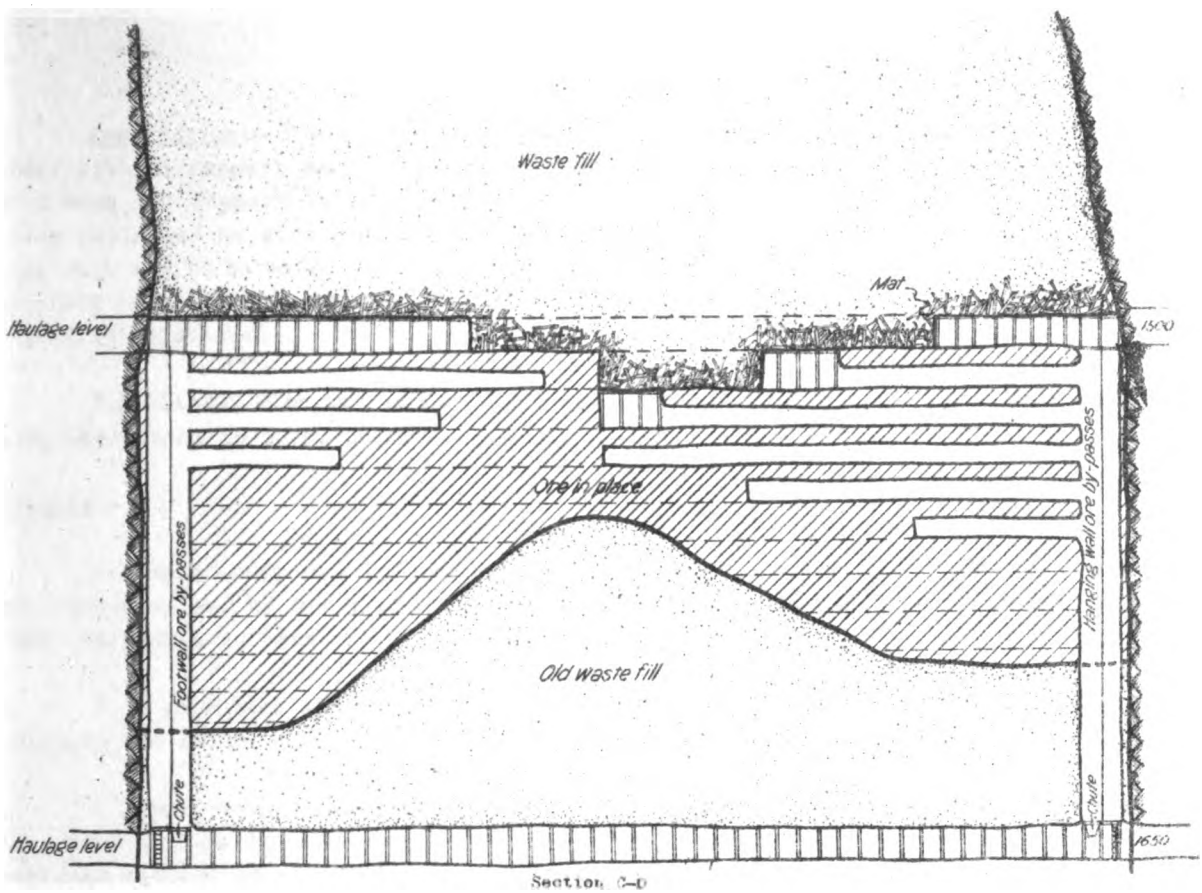
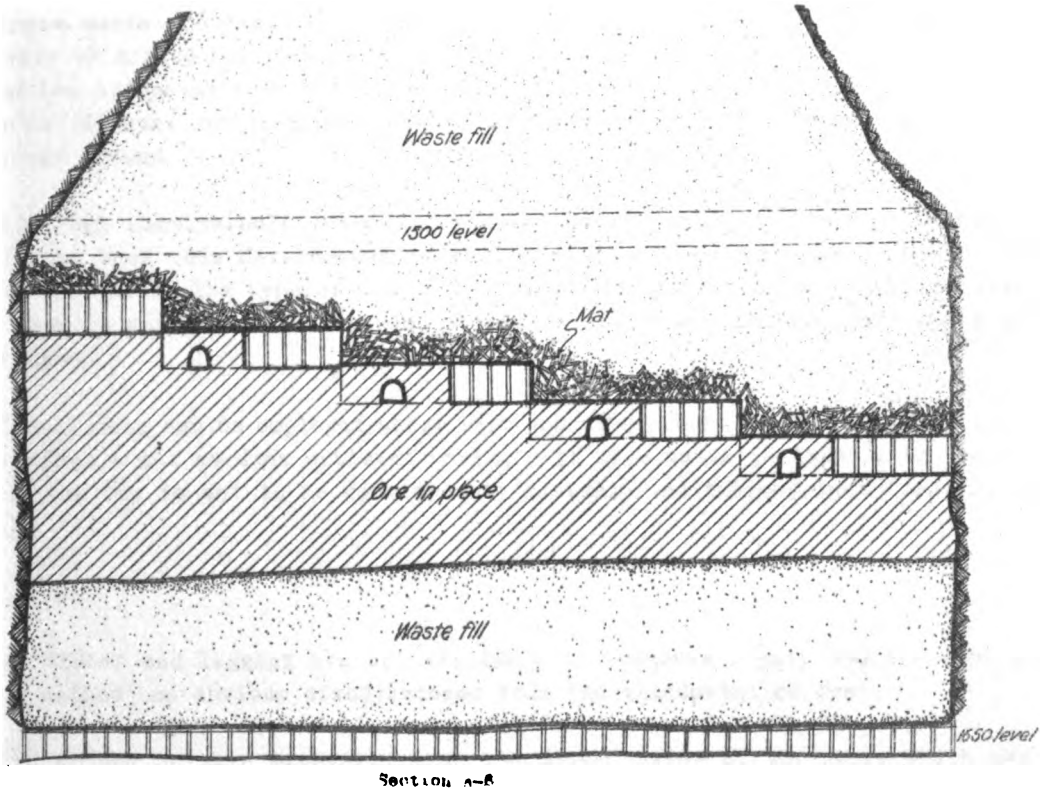


Section C-D



Section A-B

Figure 22.- Vertical sections through No. 2 top slice stope United Verde Mine Arizona.

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Top Slicing (75 to 77)

Application.- Top slicing is applicable to wide or fairly wide orebodies too weak to stand without support except over small spans and having a weak capping which will cave readily when the support is removed from beneath it and fill the excavated space tightly. The side walls may be strong or weak if the ore body is wide, but for narrow orebodies the hanging wall should be weak. Suitable timber should be available in large quantities at low or moderate cost. (Figs. 20, 21, 22.) It is obvious that caving and subsidence of the surface must be permissible.

Top slicing also has an important application in the mining out of pillars and for robbing operations in caved or broken ground.

Advantages.-

1. Top slicing is a safe method of mining heavy ground which can not be economically and safely worked by overhand-stoping methods, and is economical where timber is plentiful and reasonable in cost.

2. A very high extraction of the ore is possible with practically no dilution from the capping and walls.

3. Under proper supervision the method is safe, as evidenced by the many excellent safety records made by mines employing it. The accident rate is the second lowest for underground methods in the United States.

4. Where market conditions are such that the mine is faced with occasional shutdowns, the stopes or slices may be blasted down so that the ore body remains in good condition for resumption of operations on short notice even after idleness of considerable duration, although development headings may require considerable repair work and maintenance if close to the caved ground.

5. Although considerable preparatory development is required prior to beginning slicing operations, once this development is well started a considerable tonnage of ore is produced therefrom, and in the type of ore to which top slicing is commonly applied the cost of development ore is not greatly in excess of that of ore from slicing (see items 6 and 7, under Disadvantages).

6. Top slicing can be employed under sand and other loose surface material and does not require as clean a mat as does sublevel caving. If fine waste is mixed with the gob in sublevel caving the ore is apt to be considerably contaminated thereby (see item 10, under Disadvantages).

Disadvantages.-

1. If timber and lagging are not available in adequate supply and are expensive, the top-slicing method has obvious disadvantages from the standpoint of cost.

2. The method is more expensive than the block caving or shrinkage which may be used under similar conditions, though with these methods a lower ore extraction and higher dilution of the ore are apt to result.

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3. Where it is necessary to protect the surface against subsidence, this method would seldom be applicable, although under certain deep-mining conditions where the ore body is thin it might still be employed. Sometimes fault planes, jointing, or other lines of weakness in the capping may cause subsidence at some distance from the area immediately over the mine, while in other cases only the area directly over the excavation may be affected.

4. Ventilation is not simple with top slicing in deep mines where work is being done under a thick mat of timber; in heavy sulphide ores which oxidize when exposed to the mine air with attendant generation of heat and possibly of gas, ventilation may be an important consideration. In some cases the only solution is to serve each slice with a small, individual, booster fan, as recirculation of vitiated air must be guarded against. Forced ventilation from the surface with fans of large capacity is used in some of the deeper mines.

5. Where large amounts of old timber accumulate, as in top-slice operations, a certain fire hazard exists. Fortunately many mines employing top slicing are wet or decidedly moist, and gob fires are not of common occurrence.

6. In order to obtain a large output, a considerable number of working places are required. This may mean that working places are scattered over a considerable area and connected by a correspondingly large amount of development openings.

7. The period of development prior to production from slicing is relatively long. Rate of output can not be suddenly increased to meet market demands unless development is considerably in advance of normal production requirements.

8. Timbering and covering down the slices consumes a large part of the shift, which reduces the available time for breaking and mucking. Thus the drills and scraping equipment are idle much of the time.

9. Handling of timber, lagging, boards, and wire fencing is a large item of expense in top-slice mining, since these materials are used in large quantities and are often transported long distances in the mine.

10. If the capping breaks in large blocks which wedge together so as to leave a large open space below them, the possibility of sudden collapse presents a serious element of danger to the slicing operations below, especially if there is not a good cushion of gob between the open space and the top of the active slice (see item 6 under Advantages).

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Details of labor, explosives, and power consumption and costs per ton mined at mines using top-slicing methods

Stoping method	Mine	Ore	Width and dip of orebodies	Labor and supply consumption per ton: Labor, total underground man-hrs	Explosives, pound	Timber	Power, kw.h.	Direct mining costs per ton: Development	Stoping	Haulage and hoisting	General underground expense	Surface applicable to underground	Total	Reference I.C. list, p. 36
Top slicing and sublevel stopes	Marquette No. 2	Iron	50 to 100 ft.; 40 to 90°	1.029	0.473	0.55 lin. ft.	9.39	$0.251	$0.707	$0.149	$0.193	$0.066	$1.366	(11)
Top slicing	Mesabi No. 1	Iron	Wide, but only 10 to 30 ft. thick	1.174	.395	2.83 bd. ft.	4.74	(.729)		.128	.250	.058	1165	(75)
Top slicing	Marquette No. 5	Iron	100 ft. thick, 400-800 ft. wide	.903	.408	.672 lin. ft.	12.49	.052	.739	.210	.090	.004	1.095	(76)
Top slicing	Mesabi No. 2	Iron	Av. 15 ft. thick	1.154	.801	(?)	2.97	-	-	-	-	-	-	-
Top slicing	Mesabi No. 3	Iron	Av. 15 ft. thick; 3½°	.731	.694	1.24 lin. ft. 0.0012 cord lagging	1.86	-	-	-	-	-	-	-
Top slicing	Mesabi No. 4	Iron	Av. 40 ft. thick; 4°	.777	.463	1.06 bd. ft. 1.26 lin. ft.	3.49	-	-	-	-	-	-	-
Top slicing	Mesabi No. 5	Iron	Av. 40 ft. thick; 5°	.993	.553	1.226 bd. ft. 0.00164 cord lagging	3.36	-	-	-	-	-	-	-
Top slicing	Mesabi No. 6	Iron	1000 ft.; 6°	1.127	.562	2.21 lin. ft. 0.00325 cord lagging	4.16	-	-	-	-	-	-	-
Top slicing	Mesabi No. 7	Iron	300 ft.; 60 to 80°	1.263	.433	(?)	5.25	-	-	-	-	-	-	-
Top slicing	Mesabi No. 8	Iron	10 to 75 ft.; steep	.972	.634	1.746 lin. ft.	11.51	-	-	-	-	-	-	-
Top slicing	Mesabi No.11	Iron	Wide ore; 45°	1.386	.547	1.702 bd. ft. 3.94 lin.ft. lagging	9.39	-	-	-	-	-	-	-
Top slicing	Mesabi No 12	Iron	Wide ore; 45°	1.048	.437	1.12 bd. ft. 1.85 lin. ft. poles; 4.47 lin.ft. lagging	18.41	-	-	-	-	-	-	-
Top slicing	Mesabi No.13	Iron	Wide ore; 45°	1.018	.365	1.376 bd. ft. 3.05 lin.ft. lagging	(?)	-	-	-	-	-	-	-

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Block Caving (100 to 104)

Application.- Block caving is applicable to the mining of large thick bodies of low-grade ore of such physical character that, in caving and drawing, the ore will break up fine enough to pass the mill holes and will not pack in the chutes, and where the ratio of overburden to ore volume is too high to make opencut mining economical. It is obvious that caving and subsidence of the capping and surface must be allowable (figs. 23, 24, 25, 26, 27).

Advantages.-

1. Low mining cost per ton, approaching that for open-pit mining.

2. High rate of output is possible once the mine has been developed to the extraction stage.

3. Possibility of standardizing various operations to a high degree, thus making for efficiency and safety in mining.

4. Accident rate fairly low.

Disadvantages.-

1. Large capital expense and long period of time required for development and bringing mine into production stage.

2. Dilution of ore with waste and loss of ore, particularly around margins of an irregular orebody.

3. Necessity for very close supervision and extreme care in control of drawing operations.

4. Low grade of "Junore" in capping or marginal areas is lost.

In block caving, three things must be constantly watched and controlled:

First, the mining must be done in such a manner that excessive weight does not develop on the grizzly level. This is generally controlled by the rate at which the ore is pulled. Also, weight may develop on a line of grizzlies ahead of the undercutting. The reason for this is not definitely understood, although it can be largely prevented in most cases.

Second, the ore should be broken sufficiently in caving to be subsequently handled without further breaking. The slower the drawing rate, generally, the more the ore is broken up; also the slower the drawing rate, the more weight develops on the grizzly level. Generally a balance is taken between the two to get maximum efficiency. Should the undercutting not be done in the proper manner, a large block of ore may settle down on the undercutting level without being broken up. When this happens the expense of mining is greatly increased, or part of the orebody may be lost.

Third, the ore must be drawn in such a manner as to get maximum recovery of ore and minimum dilution with waste. The dilution may be both of the capping and of marginal rock.

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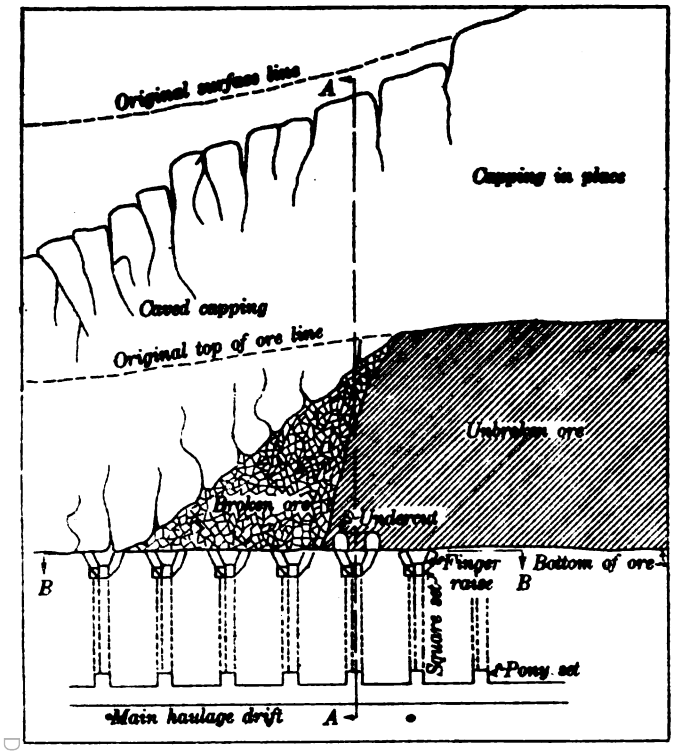
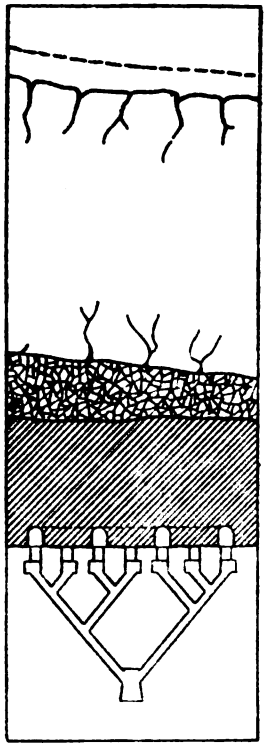
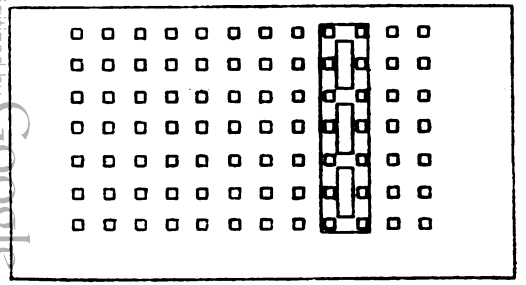


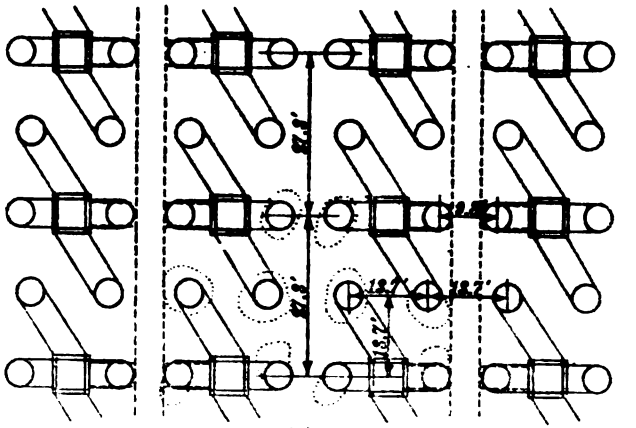


SECTION A-A



SECTION B-B

Figure 23 – Caving system used at Ruth mine (Nevada)



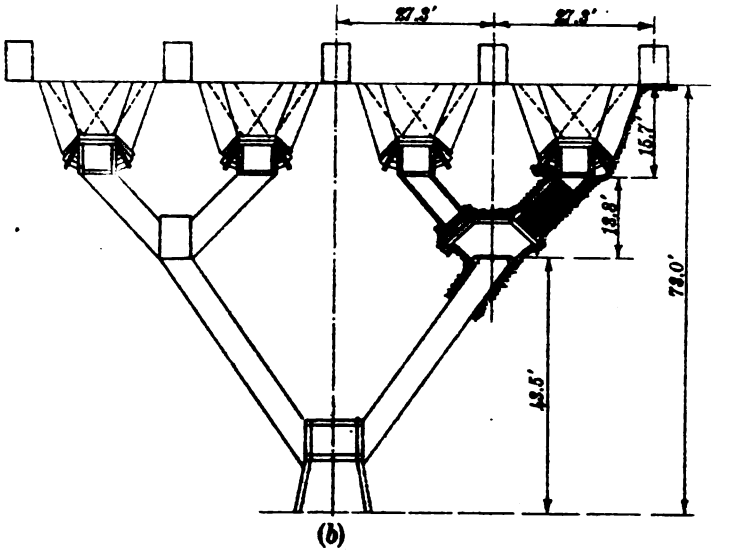


Figure 24 – (a) Plan of undercutting level showing top of branch raises. (b) Transverse section on main and branch raise system, Andes Copper Co.

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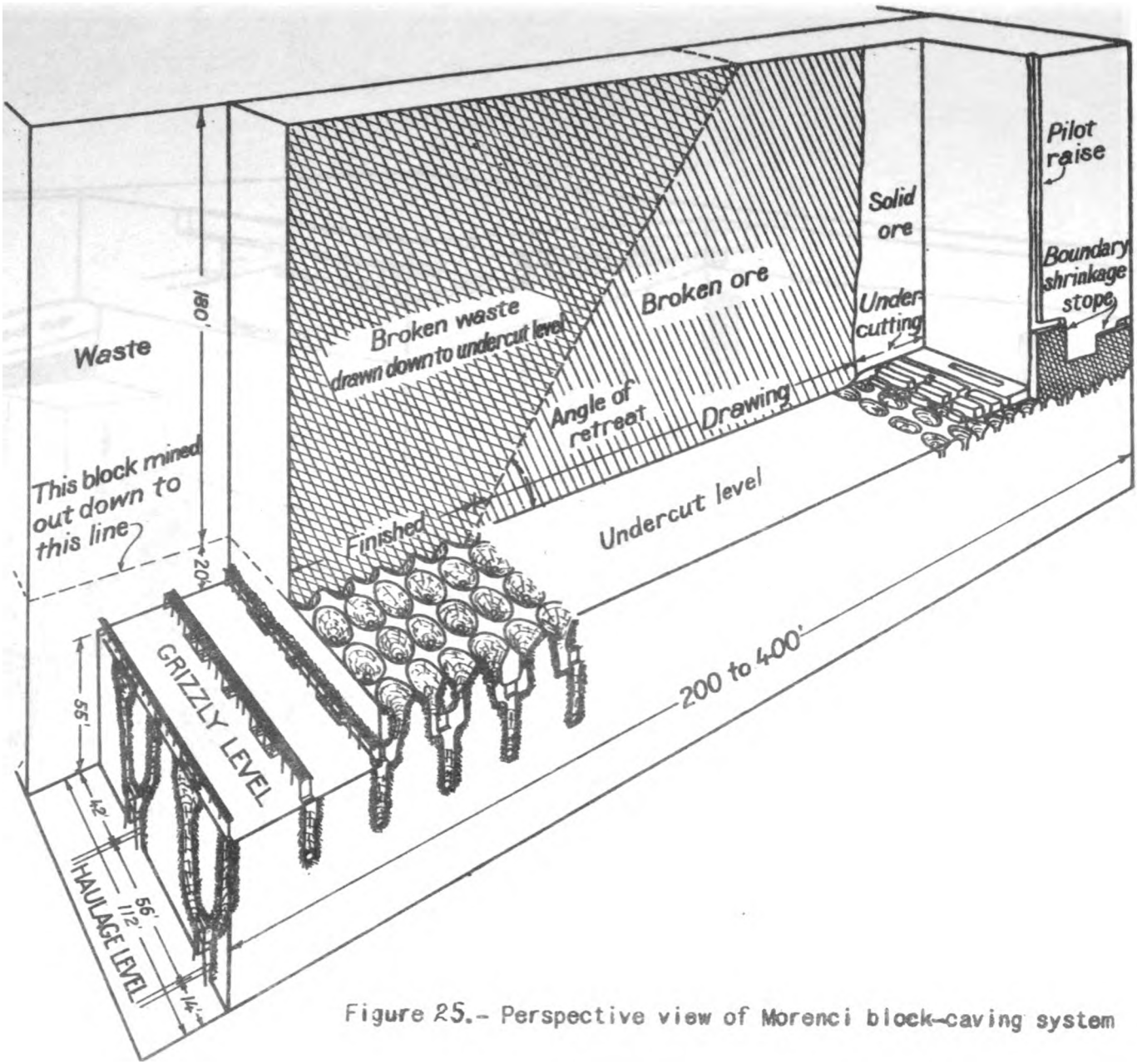

Figure 25.- Perspective view of Morenci block-caving system

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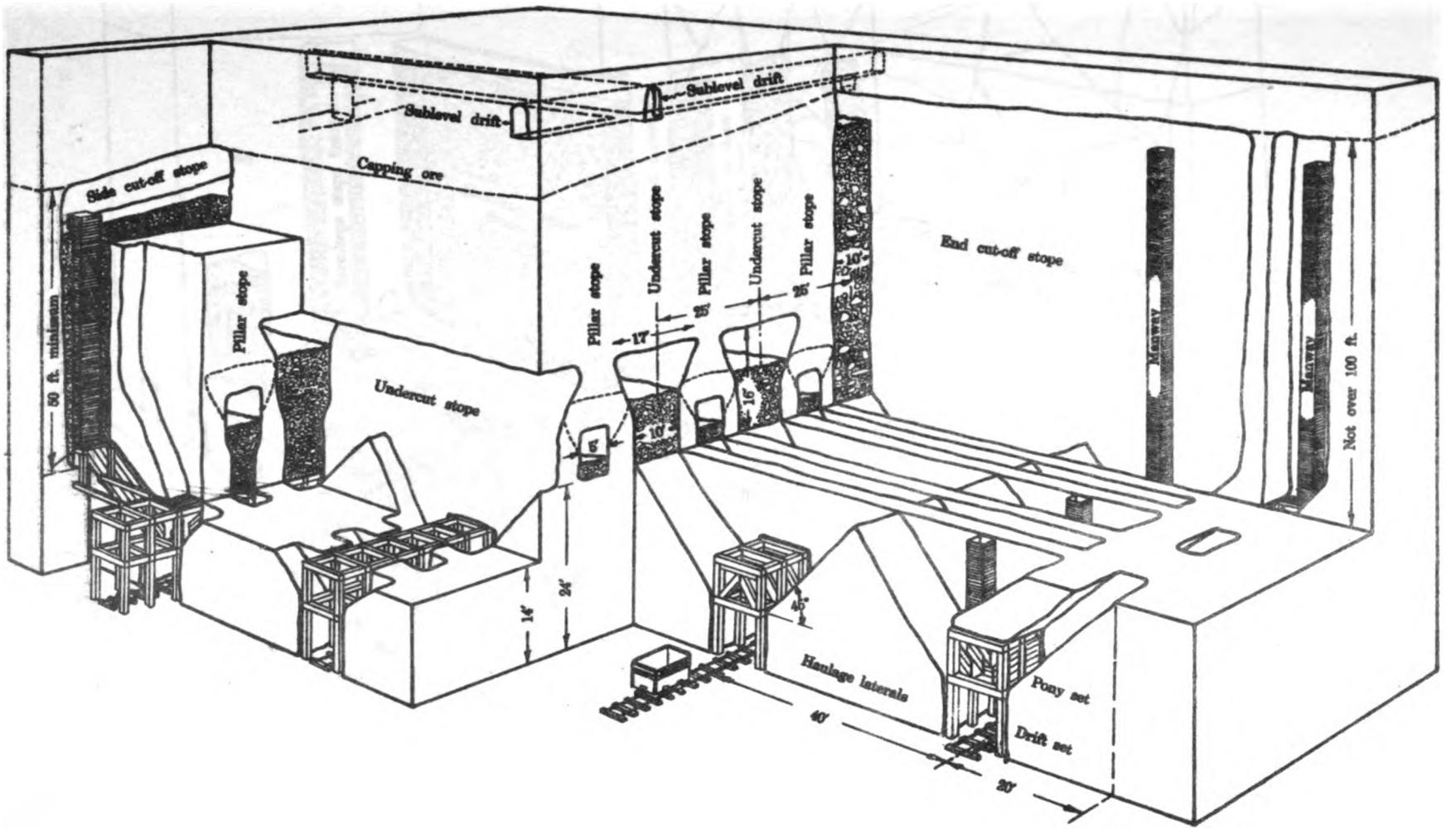

Figure 26.—Motor-haulage caving method

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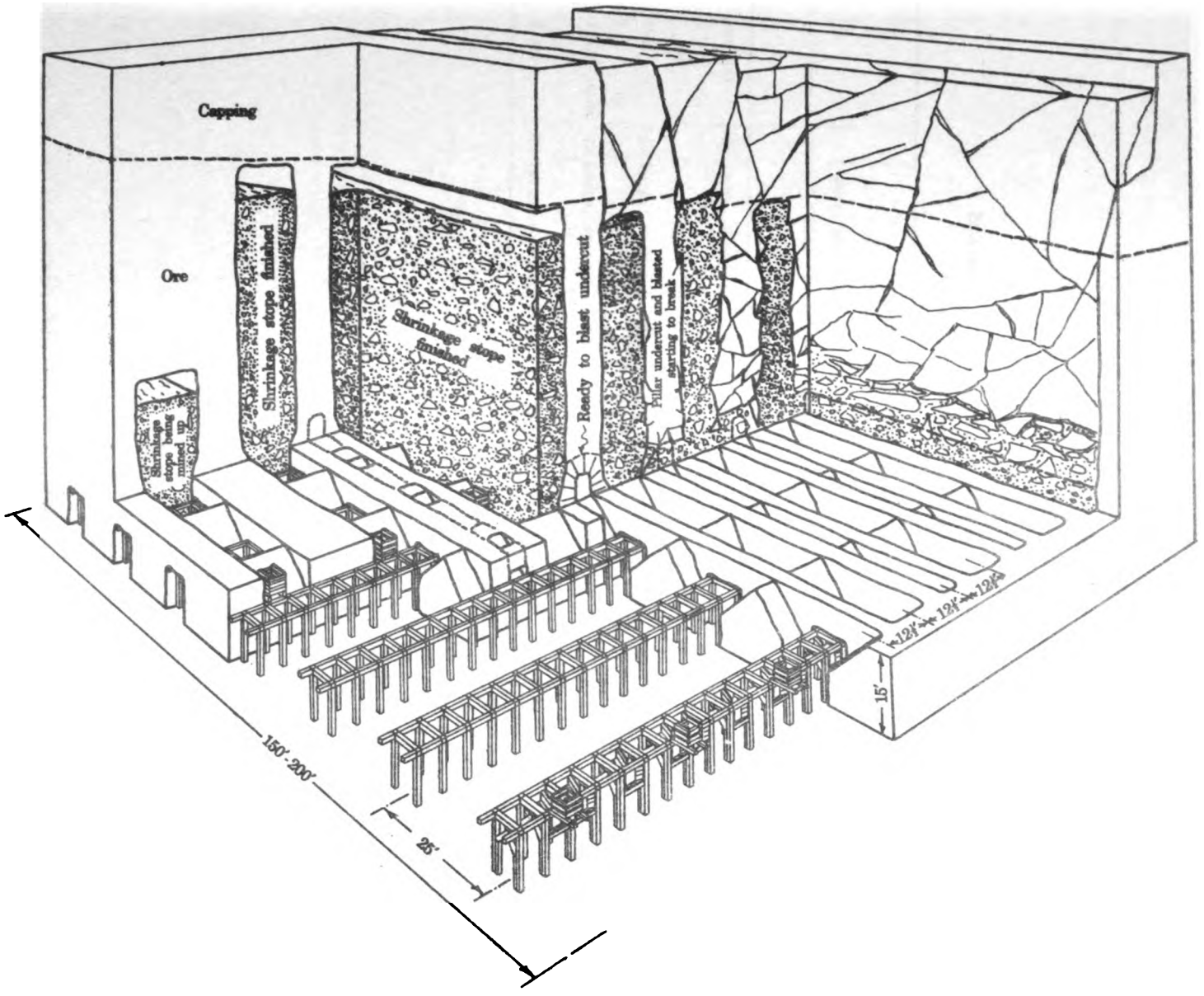

Figure 27. – Hand-tramming caving method

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Details of labor, explosives, and power consumption and costs per ton mined at mines using block-caving methods

				Labor and supply consumption per ton				Direct mining costs per ton						
Stoping method	Mine	Ore	Width and dip of orebodies	Labor, Total underground, man-hrs	Explosives, pound	Timber	Power, kw.h.	Development	Stoping	Haulage and hoisting	General underground expense	Surface applicable to underground	Total	Reference I.C. list
Block caving	Morenci	Cu	Large, massive	0.823	0.190	0.25 bd. ft.	-	$0.132	$0.108 est.	$0.100	($0.116	)	$0.456	(100
Block caving	Ray	Cu	Large, massive	.729	.319	1.88 bd. ft.	.104	.243	.111	.166	-		.624	(101
Block caving	Inspiration	Cu	Large, massive	.625	-	-	-	.211	.208	.144	.012	$0.008	.583	(102
Block caving	Miami	Cu	Large, massive	.384	.222	1.045 bd. ft.	1.90	.100	.136	.086	.057	.020	.399	(101

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Combined Underground Methods

Considerable objection has been offered to the inclusion of "combined" methods in a classification of stoping methods. However, where two or more of the typical methods are employed together in a regular scheme for mining each block of ore in a mine, it is the author's opinion that such combinations are deserving of sufficient prominence to be classified as distinct methods. This is especially true where the method contributing the greater part of the tonnage is dependent upon the other method for its successful application. Thus we have block caving combined with shrinkage stoping (fig. 28) in which the individual blocks to be caved are isolated one from the other by marginal shrinkage stopes.

Figure 29 shows shrinkage stoping combined with square-setting where, in the regular scheme of things, stopes are mined by shrinkage and each stope is separated from its neighbors by a pillar, the pillars being mined later by square-setting. Shrinkage stopes combined with pillar caving, in which stopes are separated by pillars that are later caved and drawn with the emptying of the stopes, are shown in Figure 30. We also have stopes separated by pillars; the stopes are mined by shrinkage with subsequent waste filling, and the pillars are later mined by top slicing (fig. 31). In each of these instances the major method is dependent upon the auxiliary method for its successful application.

Opencut Methods (110 to 115)

Opencut methods of mining have a wide use in the mining of surficial deposits or wide deposits having a relatively thin capping (figs. 32, 33, 34, 35). Broadly speaking, they are applicable where the ratio of overburden to ore and the nature of the overburden are such that the total cost of removing the overburden plus the cost of mining the ore by open-pit methods is less than that of mining by underground methods, such items as capital investment and interest on development expense during removal of overburden prior to the productive life of the property being taken into consideration.

Iron ore, copper ore, coal, phosphate rock, stone, sand and gravel, and other nonmetallics are mined in large quantities by opencut methods. Placer mining (except in drift placers) is also a form of opencut mining.

Opencut operations include those using hand methods, steam and electric power shovels (110, 111, 112), and drag lines. Even a brief description of each of these methods, having many variations as they do, would be too voluminous for the present paper.

Advantages.-

Opencut methods, where they can be applied, have the obvious advantage of being conducted in daylight, and where a night shift is employed flood lights may be used.

1. Rates of output may be varied within a wide range without corresponding variations in operating costs.

2. Low cost of operation on the average.

3. Mechanical methods of loading and haulage are easily applied, resulting in small labor requirements per ton produced, and ease of increasing production without large additions to operating forces.

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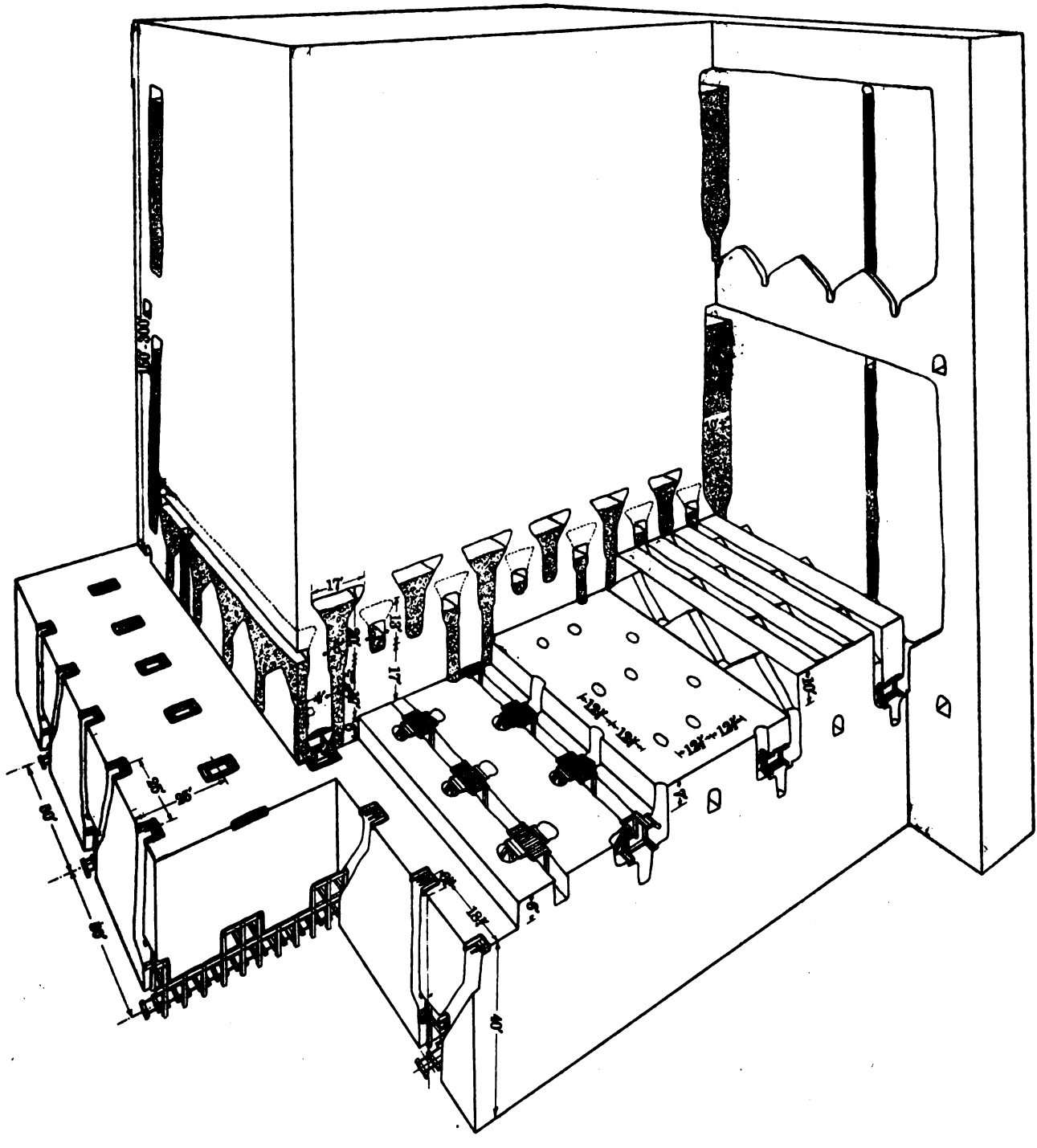

Figure 28 Sublevel undercut caving method

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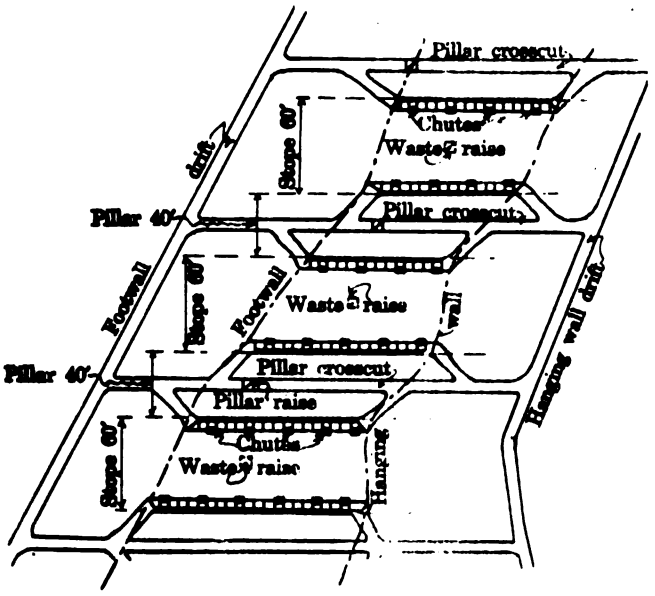
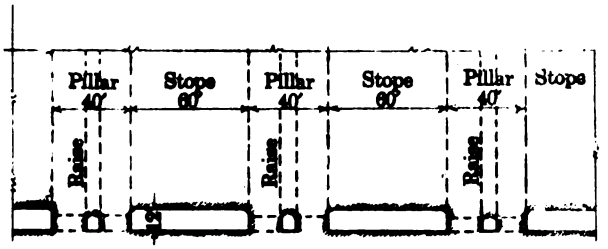
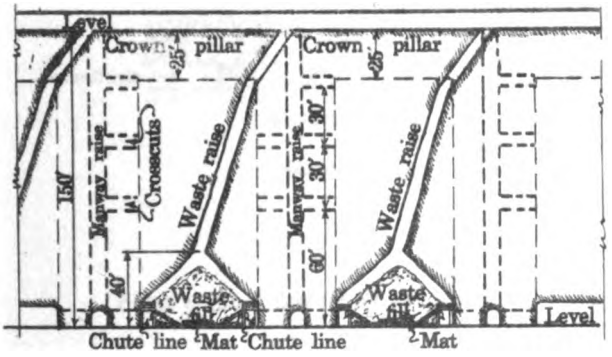


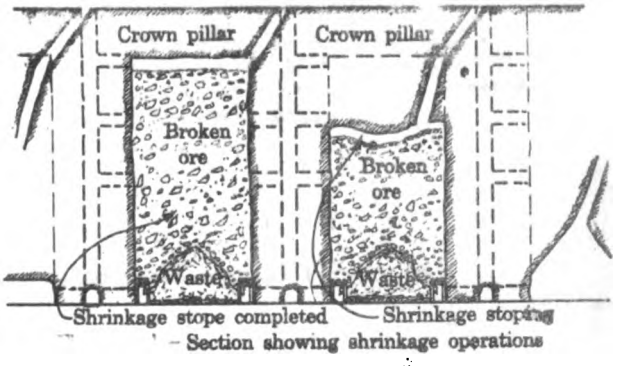
Sill floor plan showing development and chute lines



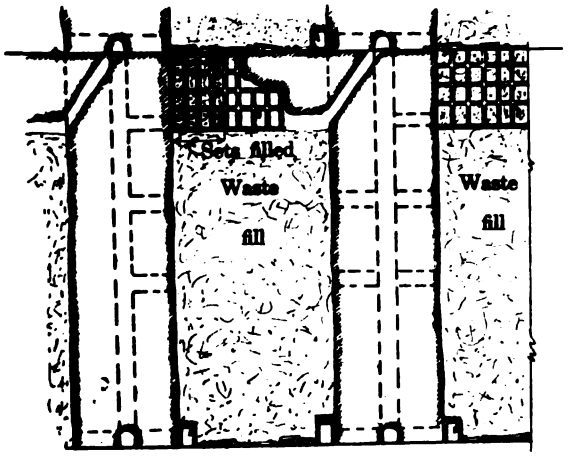
Longitudinal section showing stopes silled out



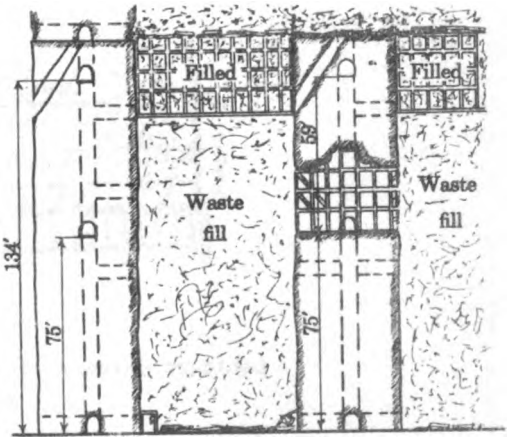
Longitudinal section showing stopes arched and filled, ready to start shrinkage stoping



Section showing shrinkage operations



Section showing mining of crown pillar by square sets



Section showing mining of stope pillar by square sets

Figure 29.- Combined methods; shrinkage stoping combined with square-setting.

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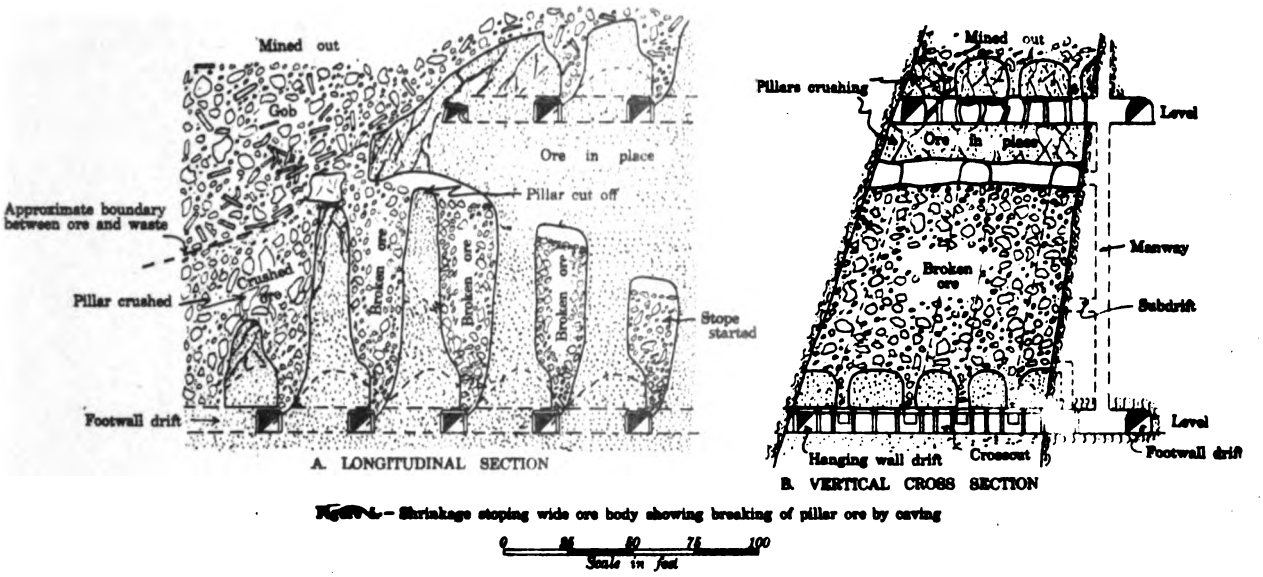

Figure 30.- Shrinkage stoping wide ore body showing breaking of pillar ore by caving

Figure 30.- Combined methods; shrinkage stoping combined with pillar caving

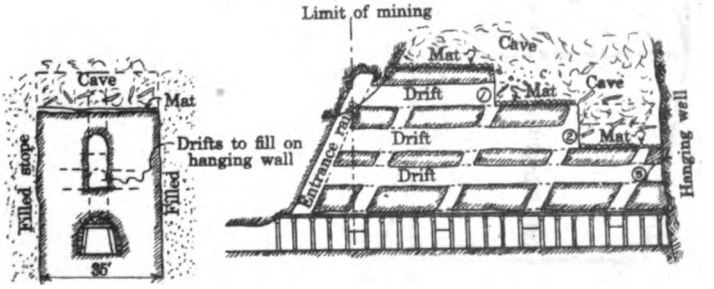

Figure 31.- Combined methods; cut-and-fill stoping combined with top slicing of pillar

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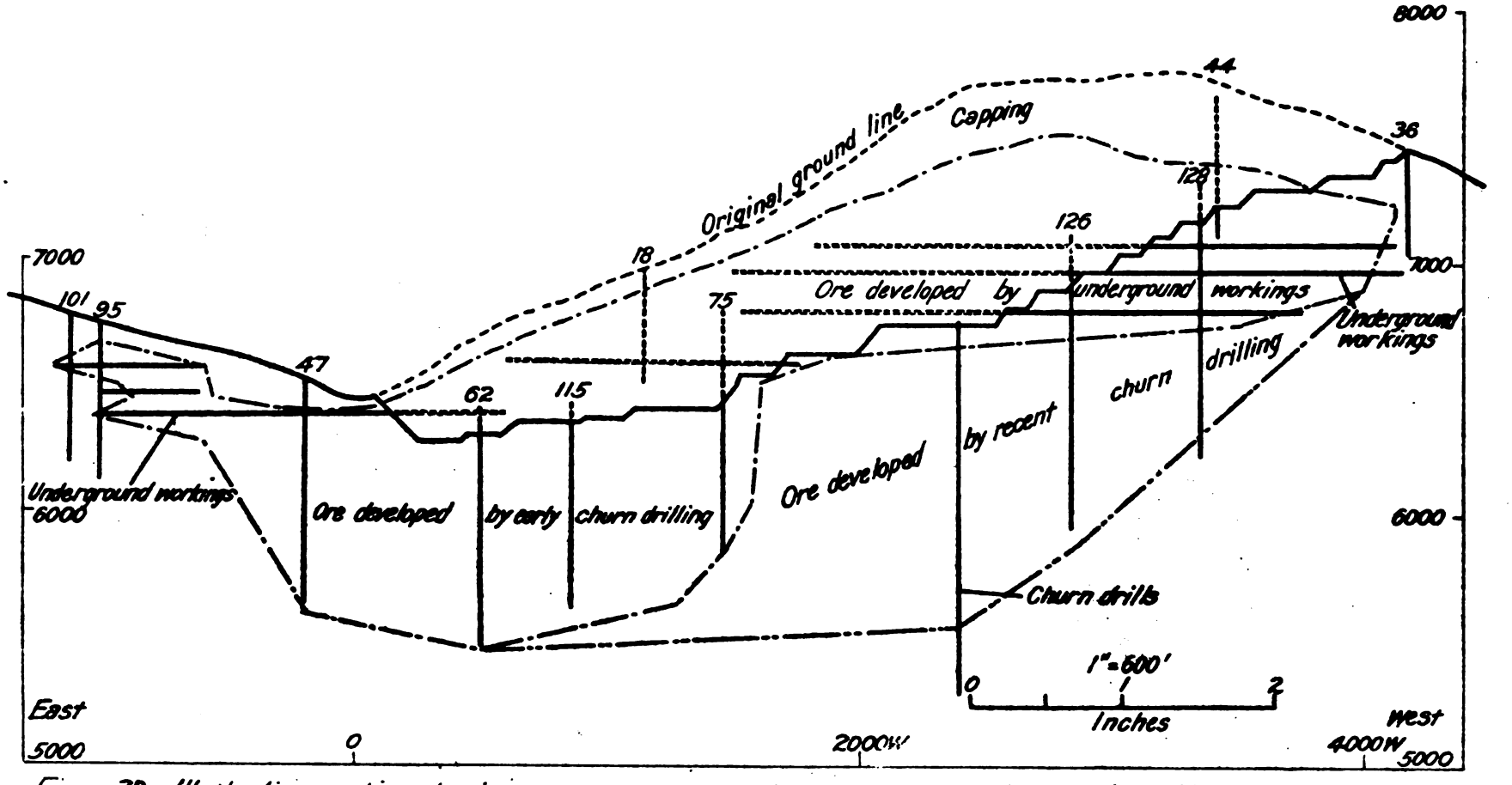

Figure 32. Illustrative section showing comparative ore development by underground workings and churn drills

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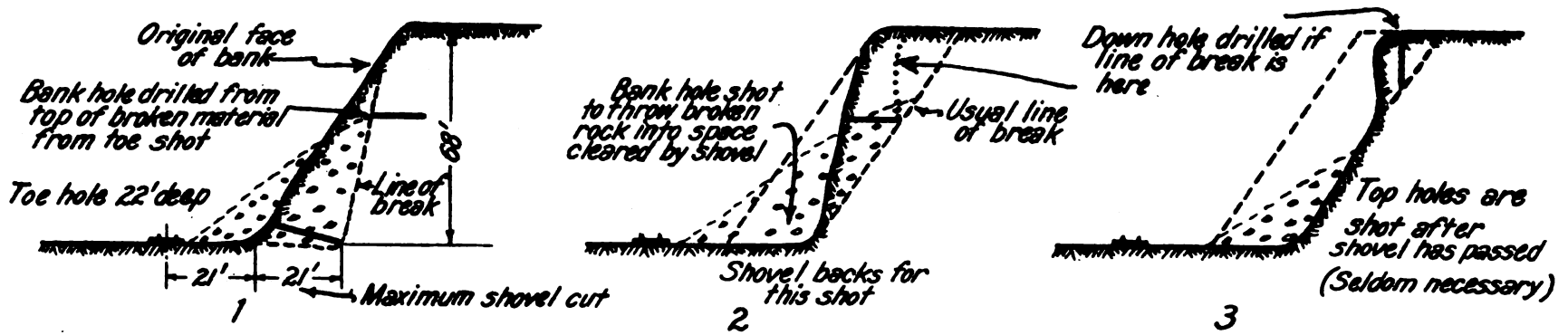
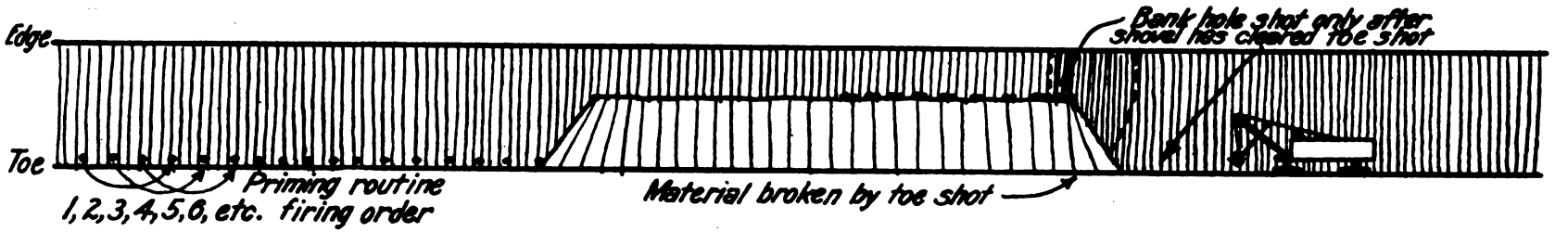
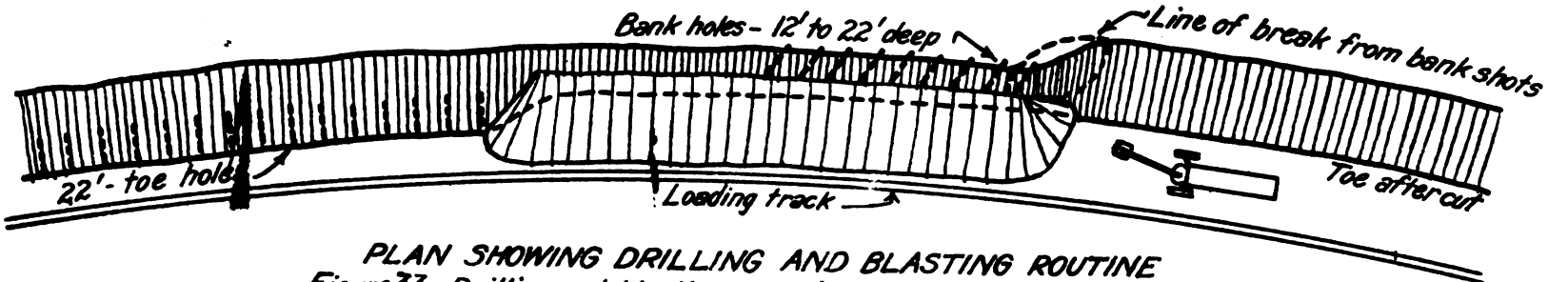

Original face of bank
Bank hole drilled from top of broken material from toe shot
Toe hole 22' deep
Line of break
88'
21'
21'
Maximum shovel cut
1
Bank hole shot to throw broken rock into space cleared by shovel
Usual line of break
Shovel backs for this shot
2
Down hole drilled if line of break is here
Top holes are shot after shovel has passed
(Seldom necessary)
3

SECTION OF BANK SHOWING BLASTING METHOD


Edge
Toe
Bank hole shot only after shovel has cleared toe shot
Priming routine
1, 2, 3, 4, 5, 6, etc. firing order
Material broken by toe shot

ELEVATION



PLAN SHOWING DRILLING AND BLASTING ROUTINE

Figure 33 - Drilling and blasting practice Utah Copper Mine

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4. Low idle or shutdown expense during periods of slack markets.

5. Safety in operation, the safety records being usually better than for most of the underground methods.

Disadvantages.-

1. Where much overburden has to be removed prior to extraction of ore, development expense, including interest on development capital prior to the productive stage, is high.

2. In severe weather, opencut work has obvious disadvantages.

3. Necessity for preventing flooding of the workings during heavy rains and spring thaws.

4. Necessity for sometimes removing large bodies of waste material within the pit area to get at ore lying beneath.

5. In deep pits a difficult problem is often presented in keeping the proper slopes and benches or berms on the sides of the pits to prevent slides and at the same time to remove no more barren material than is necessary.

6. Deep pits must have sufficient horizontal extent to permit reasonable haulage grades.

Results.- Two tables are given; one to show for the different ores, the metal yield and man-hours consumed per ton mined by the opencut method at mines that produced over $100,000 in 1929; the other gives operating costs.

Metal yield and man-hours consumed per ton mined by the opencut method at mines producing over $100,000 in 1929

Metal	Number of mines	Tons mined	Yield per ton	Man-hours per ton
Gold	0	0	0	0
Copper	7	31,563,645	20.6 lbs.	0.29
Lead-zinc	0	0	0	0
Iron	48	35,609,878	.475 ton	.39

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Operating costs

Mine	Drilling and blasting	Shovel operations	Transportation	Miscellaneous	Total	Labor	Power and supplies	Material handled, 1928	Refer I.C. list, p. 36
Utah Copper:									
Stripping, per cu. yd.	$0.060	$0.042	$0.145	$0.027	10.274	$0.127	$0.147	7,220,034 yds. waste	(110)
Mining, per ton of ore	0.027	0.019	0.054	0.018	0.117	0.043	0.075	16,558,500 tons ore	
Total, per ton of ore	0.054	0.037	0.117	0.029	0.237	0.100	0.139		
United Verde:									
Stripping, per cu. yd.	0.293	0.161	0.198	0.018	0.670	0.304 (est.)	0.118	322,538 yds. waste	(111)
Mining, per ton of ore	0.139	0.077	0.086	-	0.302	0.167 (est.)	0.065	731,488 tons ore	
Total, per ton of ore	0.258	0.145	0.160	0.008	0.571	0.301	0.117		
Chino (steam):									
Stripping, per cu. yd.	0.092	0.193	0.284	0.049	0.633	0.121	0.154	1,577,373 yds. waste	(112)
Mining, per ton of ore	0.051	0.079	0.131	0.017	0.278	0.052	0.067	1,335,476 tons ore	
Total, per ton of ore	0.155	0.301	0.458	0.074	1.025	0.195	0.148		
Chino (electric):									
Stripping, per cu. yd.	0.097	0.078	0.219	0.030	0.424	0.068	0.092	2,976,357 yds. waste	(112)
Mining, per ton of ore	0.049	0.036	0.108	0.014	0.207	0.037	0.048	2,621,340 tons ore	
Total, per ton of ore	0.158	0.125	0.357	0.048	0.688	0.114	0.092		
Weighted averages:									
Stripping, per cu. yd.	0.079	0.073	0.180	0.030	0.368	0.117	0.134	12,096,302 yds. waste	
Mining, per ton of ore	0.035	0.027	0.066	0.017	0.145	0.047	0.070	21,246,804 tons ore	
Total, per ton of ore	0.080	0.068	0.169	0.034	0.354	0.113	0.147		

RECENT PROGRESS IN MINING PRACTICE

Improvement in recent years in underground mining practice has been in three principal directions: In the application of the mining method best suited to the individual conditions; in increased use of mechanical and electrical equipment; and in better organization underground so as to get greater efficiency per man and per machine.

Illustrative of the first are numerous recent changes from shrinkage stoping to cut-and-fill stoping, changes from shrinkage to sublevel stoping, from square-setting to top slicing, from top slicing to sublevel caving, in each case better results being achieved due to substituting a method better suited to local conditions.

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Not only have radical changes been made by substitution of an entirely different mining method, but minor variations of mining methods and practice have resulted in safer and more economical operation.

The causes to which these changes in mining methods may be attributed are: Increased depth of workings; increased size of orebodies worked; reduction in assay value of ore; demand for increased output; increased cost of labor and supplies; and decrease in market value of products.

These same reasons will be responsible for future improvements in mining methods and practice, as the necessity for lower mining costs increases.

As an aid to the operator in working out his problems, the United States Bureau of Mines is disseminating descriptive reports and data, prepared by officials of the principal metal mines in the United States, and published as Information Circulars for free distribution. (See list at end of this paper.)

PRESENT TENDENCY TOWARD IMPROVEMENTS IN MINING METHODS

Much improvement has been made in mining methods during the past decade, but greater progress should be made during the next 10 years. Why? Because present low metal prices will not permit certain mines to continue operations except with improved practice and with the introduction of methods better suited to special conditions. Improved practice should include better underground organization and the training of workmen to greater efficiency.

Progress in mining methods will probably be in the direction of eliminating filling with waste, the decreased use of square-sets, and greater application of the retreating system of stoping. The tendency is toward the vertical alignment of stopes rather than in the direction of horizontal development. A system may be developed eventually by which large orebodies may be mined in vertical slices, starting from the extreme ends or sides of the deposit and retreating laterally, and from lower levels upwards, rather than by the usual method of mining horizontal slices starting at the upper levels and near the shaft. Where the walls are fairly solid, vertical slices could be mined by the sublevel stoping method; and where the walls are weak a method something like the top-slice method might be developed. There are places where such a method may be impracticable, but a start is already being made in this direction, and engineers should consider seriously such a method in planning future operations.

Another reason for a change in present methods at some mines is the fact that they must be worked deeper to develop new ore reserves, which will increase mining costs unless some radical improvement is made in present practice.

METHOD OF FIRST DEVELOPING AND MINING UPPER LEVELS

The more common practice is to open and mine the upper levels first - often, it is true, to work several levels at the same time - and to maintain production by sinking the shaft deeper from time to time and opening lower levels.

Among the chief reasons for the adoption of this method may be mentioned: Lack of knowledge regarding the deposits at depth and in lateral extent; necessity for speed in

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opening the mine and bringing it into profitable production; need for using a relatively small capital outlay prior to profitable operation. Many companies do not have capital sufficient for exploitation in any other manner.

Some of the disadvantages of this more common practice which have brought about the adoption of the opposite procedure of starting at the bottom and outer limits of the deposit are as follows:

First, high rock pressures often develop on the lower levels. As mining operations progress downward, the maintenance of hoisting shafts, airways, and drifts adjacent to worked-out ground becomes an increasing item of expense, and during mining operations workings often require increased support and in some cases are difficult to support.

Second, where stopes are filled concurrently with the mining of the ore, or subsequently, the waste from development on the lower levels is usually relied upon to furnish a considerable portion of the fill. This entails hoisting of waste from lower to higher levels, often interferes with hoisting and tramming of ore, and may mean added expense on several levels for separate ore and waste pockets, for hoisting equipment, and perhaps even for larger shafts.

Third, breaks to the surface produced by ground movement early in the life of the operation may entail heavy pumping expense over the entire life of the mine, due to entrance of surface waters.

Fourth, the ore itself may be wet, and when mining from the top downward drainage will be poor and the mine will be wet on all levels.

Fifth, by this method, toward the end of the life of the mine the costs are apt to be high. One of the companies which is planning the reverse order of mining is at present suffering from high costs at one of its mines which is in its old age. When a mine has just been developed to the productive stage, all the early conditions are generally at their best for securing low mining costs. Ground movement and subsidence have not started, and problems of support are less serious than later.

In mining from the top downward, hoisting costs are at their lowest during the early life of the mine, the flow of water may or may not be minimum but the static head against which the water must be pumped is constantly increasing. Often as mining progresses to successively lower levels, these problems become increasingly difficult of solution. Thus, considerably before the orebody is all mined, the cost of production may reach the point where mining can no longer be profitably done.

METHOD OF FIRST DEVELOPING AND MINING LOWER LEVELS

Several instances have been noted where development and mining have been or are to be started at the lowest levels on the orebody or on a block of considerable vertical depth, followed by development and mining on successively higher levels.

By mining the lower levels first, troubles incident to ground movement, caving, and subsidence will not interfere with active mining operations. Also, waste from development of upper levels can always be disposed of readily and cheaply by gravity transfer, and

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in the event of a heavy inrush of water, or serious breakdown of pumping equipment or source of power, the worked-out lower levels will furnish a large storage reservoir.

In the bottom levels operating difficulties may arise, first in wide orebodies if the ore is mined by wide horizontal slices. Where large areas are mined and filled, the filling can not be expected to offer sufficient support to prevent major subsidence, if the pressures involved are so great that movement can take place by the squeezing of the fill. Once large-scale movement starts, breaking and crushing of ore above the lower worked-out areas is bound to occur, often making mining on the upper levels difficult and expensive. This can be prevented by beginning at the end or margins of the orebody, or by starting sections or blocks and distributing the stoping along a roughly vertical plane, rather than over wide horizontal areas. In this way mining always would be retreating from areas of possible subsidence and crushing.

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BUREAU OF MINES INFORMATION CIRCULARS IN MINING PRACTICE
LISTED ACCORDING TO PRINCIPAL STOPING METHODS

Open Stoping

Ref.	I.C.	
(1)	6092	Cummings, A. M. Method and Cost of Mining Magnetite in the Mineville District, N. Y.
(2)	6113	Netzeband, Wm. F. Method and Cost of Mining Zinc and Lead at No. 1 Mine, Tri-State Zinc and Lead District, Picher, Okla.
(3)	6121	Netzeband, Wm. F. Method and Cost of Mining Zinc and Lead at Mine No. 2, Tri-State District, Picher, Okla.
(4)	6138	Eaton, Lucien. Method and Cost of Mining Hard Specular Hematite on the Marquette Range, Michigan.
(5)	6149	McNaughton, C. H. Mining Methods of the Tennessee Copper Co., Ducktown, Tenn.
(6)	6150	Banks, Leon M. Mining Methods and Costs in the Waco District.
(7)	6159	Keener, Oliver W. Method and Cost of Mining at Barr Mine, Tri-State Lead and Zinc District.
(8)	6160	Poston, Roy H. Method and Cost of Mining at No. 8 Mine, St. Louis Smelting and Refining Company, S. E. Missouri District.
(9)	6170	Jackson, Chas. F. Methods of Mining Disseminated Lead Ore at a Mine in the S. E. Missouri District.
(10)	6174	Netzeband, Wm. F. Method and Cost of Mining Zinc and Lead at No. 3 Mine, Tri-State District, Crestline, Kans.
(11)	6179	Eaton, Lucien. Mining Soft Hematite at Mine No. 2 of the Marquette Range, Michigan.
(12)	6180	Eaton, Lucien. Mining Soft Hematite by Open Stopes at Mine No. 1, Menominee Range, Michigan.
(13)	6193	Jackson, Chas. F. Mining Ore in Open Stopes, Central and Eastern United States.
(14)	6239	Coy, Harley A. Mining Methods and Costs, American Zinc Co. of Tennessee, Mascot, Tenn.
(15)	6286	Keener, Oliver W. Methods and Costs of Mining at the Hartley-Grantham Mine, Tri-State Zinc and Lead District.
(16)	6361	Kniffin, Lloyd M. Mining and Engineering Methods and Costs of the Hanover Bessemer Iron and Copper Co., Fierro, N. Mex.
(17)	6369	Schaus, O. M. Mining Methods and Costs at the Montreal Mine, Montreal, Wis.
(18)	6397	Kegler, Vern L. Mining Methods of the Ducktown Chemical and Iron Co., Mary Mine, Isabella, Tenn.
(19)	6402	Pierce, A. L. Mining Methods and Costs at the Spring Hill Mine, Montana Mines Corporation, Helena, Mont.
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(21)		Howbert, V. D., and Bosuston, R. Mining Methods and Costs at Presidio Mine of the American Metal Co. of Texas. A.I.M.E., T. P. 334, 1930, 15 pp.

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(27) 6260 Nelson, W. I. Mining Methods and Costs at Engels Mine, Plumas County, Calif.
(28) 6276 Elmer, Wm. W. Mining Methods and Costs at the Black Butte Quicksilver Mine, Lane County, Oreg.
(29) 6284 Heizer, O. F. Method and Cost of Mining Tungston Ore at the Nevada-Massachusetts Mines at Mill City, Nev.
(30) 6293 Jackson, Chas. F. Shrinkage Stoping.
(31) 6294 Reeder, Edwin D. Method and Cost of Mining Fluorspar at Rosiclare, Ill.
(32) 6322 Henry, R. J. Mining Methods and Costs at the Teck-Hughes Gold Mines, Ltd., Kirkland Lake, Ontario.
(33) 6327 Hezzelwood, George W. Mining Methods and Costs at the Consolidated Cortez Silver Mine, Cortez, Nev.
(34) 6384 Cronk, A. H. Mining Methods of the Rosiclare Lead and Fluorspar Mining Co., Rosiclare, Ill.
(35) 6390 Graff, W. W. Mining Practices, Methods, and Costs at Mine No. 4 of the Marquette Range, Michigan.
(36) 6413 Youtz, Ralph B. Mining Methods at the Eighty Five Mine, Calumet and Arizona Mining Co., Valedon, N. Mex.
(37) 6464 Dickson, R. H. Methods and Costs of Mining Copper Ore at the Verde Central Mines, Inc., Jerome, Ariz.

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(45) 6145 Richert, George L. Mining Methods at Minas de Matahambre, Matahambre, Pinar del Rio, Cuba.
(46) 6247 Catron, William. Mining Methods, Practices and Costs of the Cananea Consolidated Copper Co., Cananea, Sonora, Mexico.
(47) 6289 Lavender, H. M. Mining Methods at the Campbell Mine of the Calumet and Arizona Mining Co., Warren, Ariz.
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(49) 6368 Matson, J. T., and Hoag, C. Mining Practice at the Pecos Mine of the American Metal Co. of New Mexico.
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(51) 6416 Vanderburg, W. O. Mining Methods at the Block P Mine of the St. Joseph Lead Co., Hughesville, Mont.

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(56) 6250 D'Arcy, Richard L. Mining Practices and Methods at the United Verde Extension Mining Co., Jerome, Ariz.
(57) 6290 Hewitt, E. A. Mining Methods and Costs at the Park Utah Mine, Park City, Utah.
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(59) 6360 Wade, James W. Mining Methods and Costs at the Tintic Standard Mine, Tintic District, Utah.

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(61) 6371 Dailey, M. J. Methods and Costs at the Silver King Coalition Mines Co., Park City, Utah.

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(64) 6407 Brown, U. E. Mining Methods of the Bunker Hill and Sullivan Mining and Concentrating Co., Kellogg, Idaho. (See also reference 46.)

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(70) 6232 Foreman, C. H. Mining Methods and Costs at the Hecla and Star Mines, Burke, Idaho.

(71) 6238 Wethered, C. E., and Coady, Leo J. Mining Methods at the Morning Mine of the Federal Mining and Smelting Co., Mullan, Idaho.

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(75) 6325 Haselton, W. D. Underground Mining Practices and Costs at a Mesabi Range (Minn.) Mine Using the Top-Slicing System.

(76) 6380 Graff, W. W. Mining Practices, Methods and Costs at Mine No. 5 of the Marquette Range, Michigan.

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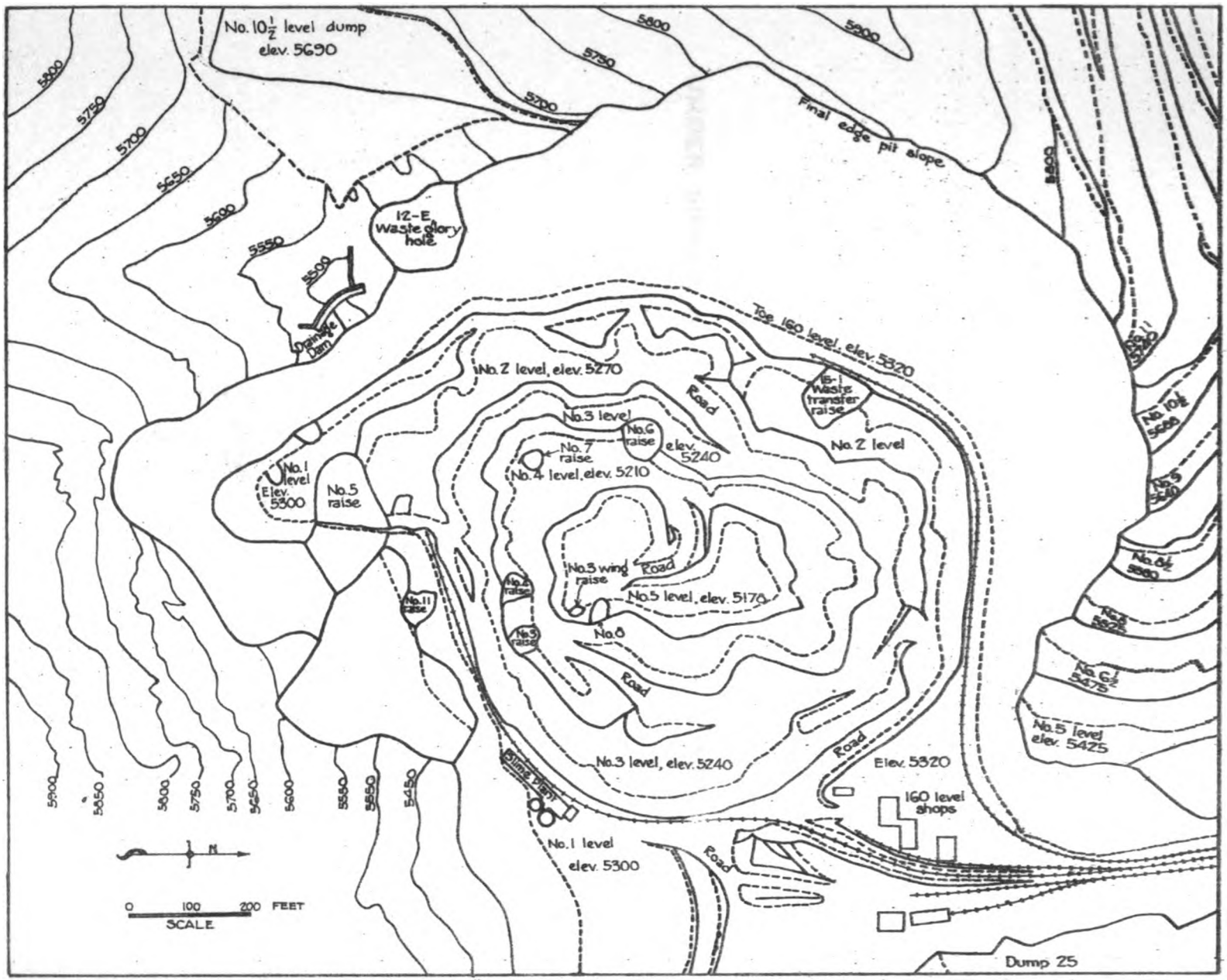

FIGURE 34 PLAN OF UNITED VERDE PIT. JULY 1, 1929

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